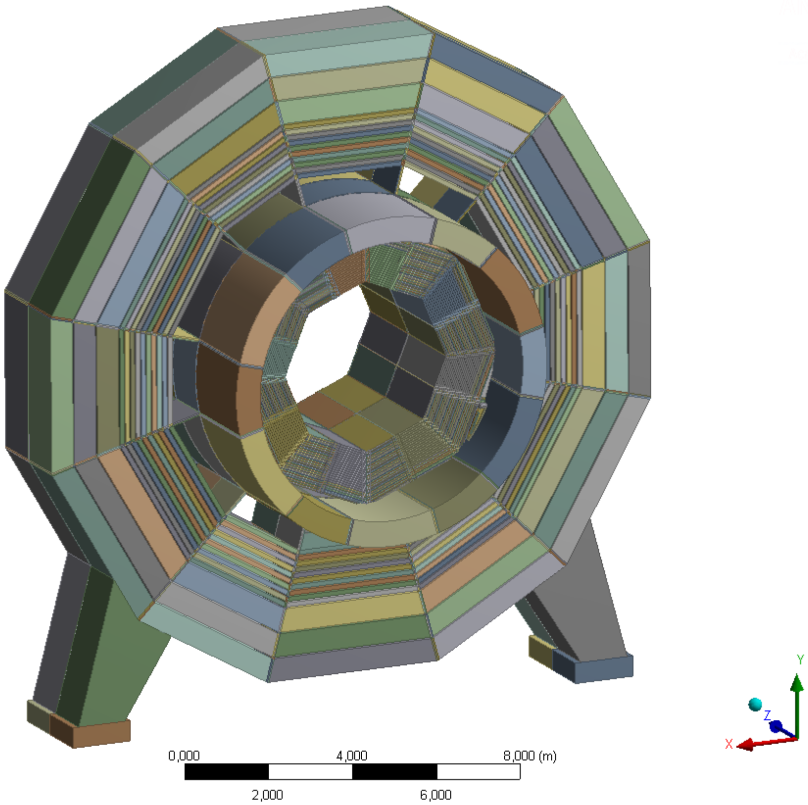
Optimisation of the AHCAL Structure

2nd Update



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ILD Integration Meeting
Hamburg, 2019-02-11

Outline

- Reminder:
  - Developed method for numerical simulation of response of complex and detailed structure to earthquake excitations
  - ECAL requested reduction of static and dynamic deformations in order to maintain tight gaps between modules
  - Study weak points, reinforce and optimise AHCAL structure
  - Begin with update of structure dimensions
- Geometry – Comparision old and new Geometry
- Lock back on the last optimisation study
- The new AHCAL Geometry in Detail
- 2nd Study on the reinforcements of the AHCAL
- Characterisation of the favourite geometry setup with static and simplified dynamic loads
- Summary and next steps

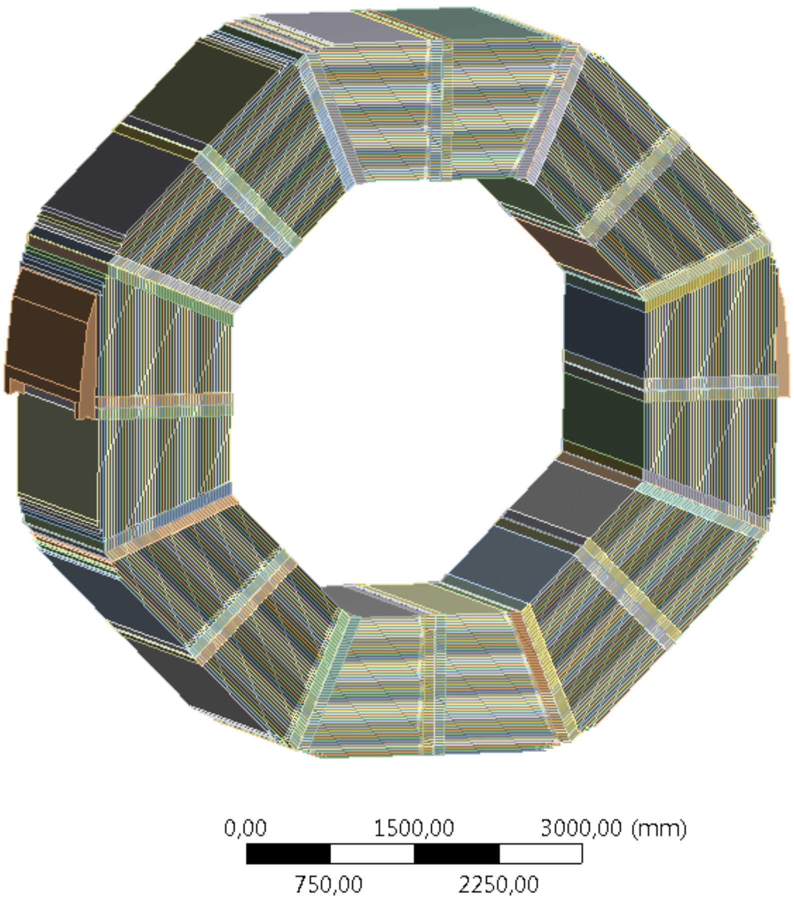
Geometry – Comparision old and new Geometry

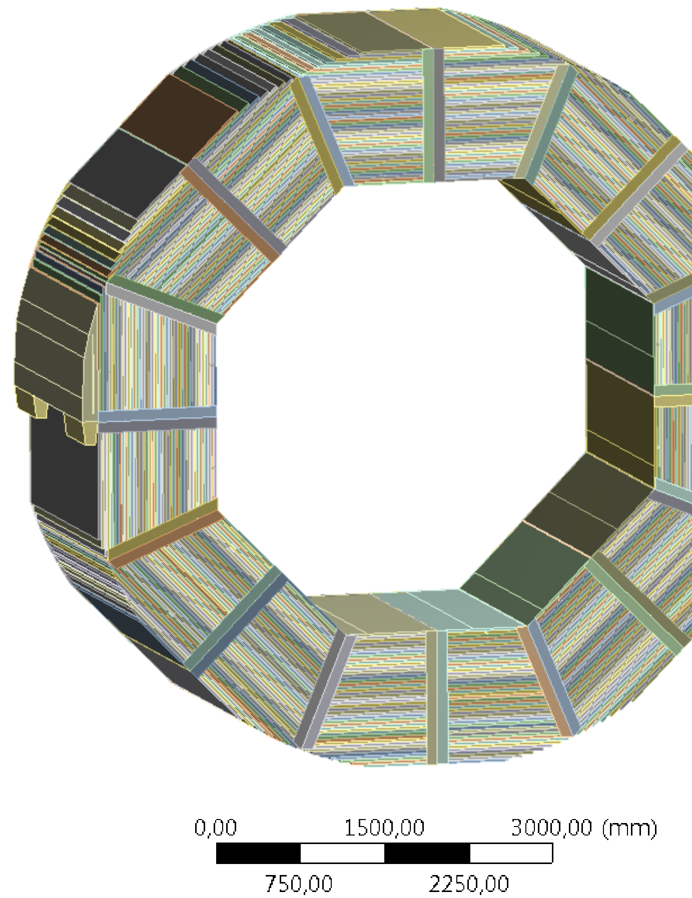
	Old	New
Plate Thickness	16mm	19mm
Number of Plates	**49 Layers** with: => 46 "full" layers => 3 "reduced" layers	**44 Layers** with: => 37 "full" layers => 7 "reduced" layers
Periodicity/Pitch	Every **26,5mm**	Every **28,0mm**
AHCAL Mass (total)*	262.108kg	291.953kg
AHCAL Length	**2.160mm**	**2.350mm**
AHCAL Outer Radius	3.392,5mm 1.445mm	3.349mm 1.291mm
AHCAL Inner Radius	1.947,5mm	2.058mm
Connection of AHCAL Segments	Coverplates: - 200mm (width) - 15mm (thickness)	Coverplates: - 200mm (width) - 15mm (thickness) Backplates: - 10mm (thickness)

* Detector mass about 16,82kg/m² (corresponds to thin cassettes) included and ECAL mass not included

Geometry – Comparision old and new Geometry

- Left, old geometry - right, new geometry

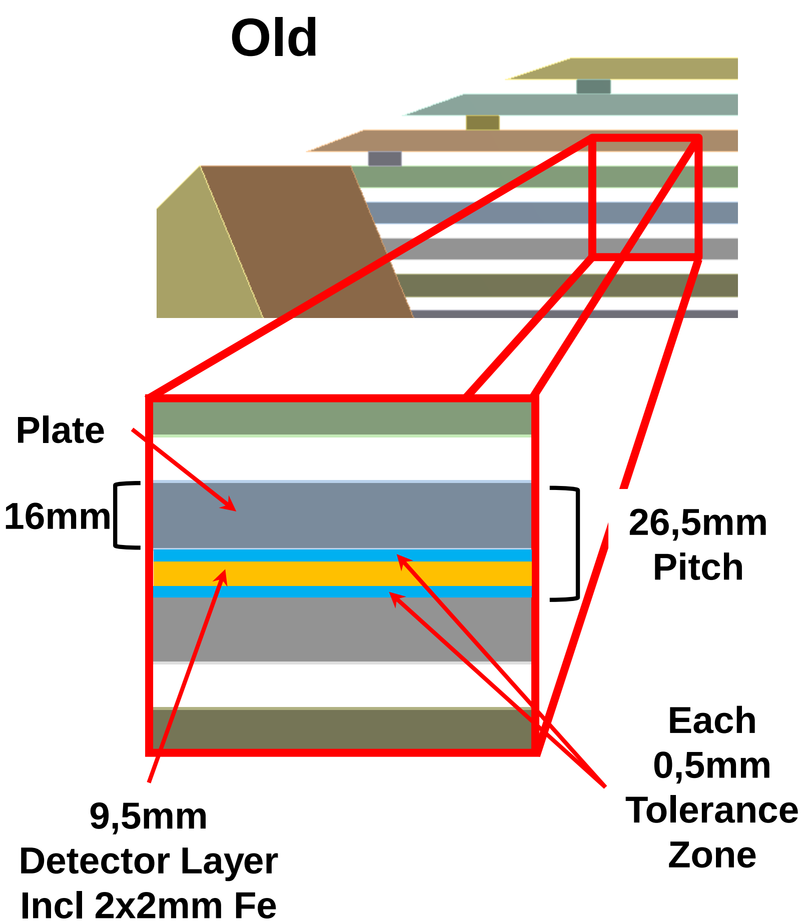


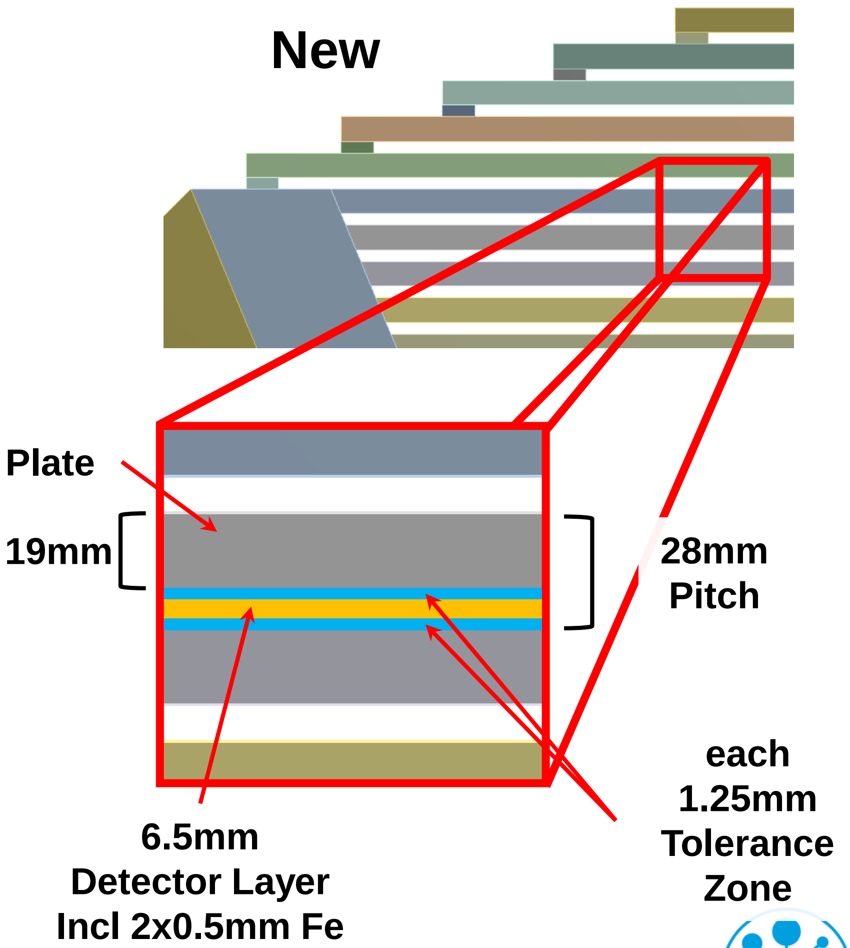


Geometry – Comparision old and new Geometry

- Definition Periodicity / Pitch in Detail

+ 3mm in absorber
-- 3 mm i cassette
+ 1.5 mm tolerance





Geometry – Summary old vs. new Geometry

- Small changes in the inner and outer diameter (see slide #3)
- Reduction of the space for the AHCAL-Detector about 154mm (due to new values for the inner and outer radius)
- Increase the plate thickness from 16mm to 19mm
- Change screw size from M10 to M12 (Coverplates)
- Therefore an reduction of the total number of plates per segment (see slide #3)
- Increase of the total lenth from 2.160mm to 2.350mm
- Introduction of additional spacer in the inner and outer areas of the AHCAL Ring
  => more overall stiffness and better flow of forces in the structure near the ECAL-Loads and the Support-Forces/-Moments

Performance and Cost Impact

- The simulation model has the DBD dimensions since long time
- The costing was also done with the dimensions of the simulation model
  - Using a cylindircal approximation and a barrel endcap scale factor
- The reduction in total depth mentioned here will therefore NOT reduce the containment and performance furher
- The increase in tolerance reduces the total amount of steel and number of layers by 6% (1.5mm out of 26.5mm)
  - The costing will be updated accordingly
- This is identical for TESLA and Videau structures and should add some point be introduced into the simulation model consistently

Lock back – Optimisation cycles on the new geometry

- To identify the optimal layout for the AHCAL-Geometry, we did some studies of various concepts
- 10 different setups were created and compared:

Slide #09,
Mini-Workshop on
ILD Infrastructure,
Tsukuba,
2018-11-29

- Following Geometric Modells are tested (with all detector loads)
  1. Shell, without any Spacer, Coverplates (t=15mm, w=200mm) at front and back side
  2. Shell, Spacer, Coverplates (t=15mm, w=200mm) at front and back side
  3. Shell, Spacer, Backplates (t=10mm) and Coverplates (t=15mm, w=200mm) at front
  4. As 2., Coverplate thickness doubled (t=30mm, w=200mm)
  5. As 2., Coverplates width doubled (t=15mm, w=400mm)
  6. As 5, Coverplate thickness doubled (t=30mm, w=400mm)
  7. As 2., small Coverplates (t=15mm, w=200mm) and wider Coverplates (t=15mm, w=400mm)
  8. As 2., less Spacer, all Spacer across 6 layer, ECAL-Geometry
  9. As 8. all Spacer across 6 layer, ECAL-Geometry
  10. As 9. and 3., Spacer (as 9.) and Backplates (as 3.)
- Questions:
  - Max. deformation and max. stresses (Mises) under own weight
  - First three Eigenmodes to estimate the dynamic behaviour

Lock back – Static and Modal Results

	Max. Deform.	Max. Equ. Stress*	1. Mode	2. Mode	3. Mode
1. Case	3,70mm**	350MPa	2,91Hz	5,19Hz	7,67Hz
2. Case	3,33mm	310MPa	3,06Hz	5,25Hz	8,14Hz
3. Case	2,00mm	440MPa	5,70Hz	9,53Hz	10,44Hz
4. Case	3,10mm	300MPa	3,16Hz	5,42Hz	8,40Hz
5. Case	2,60mm	245MPa	3,60Hz	6,15Hz	9,52Hz
6. Case	2,34mm	234MPa	3,80Hz	6,48Hz	10,00Hz
7. Case	3,10mm	260MPa	3,24Hz	5,54Hz	8,56Hz
8. Case	3,64mm	225MPa	2,91Hz	5,17Hz	7,71Hz
9. Case	2,74mm	270MPa	3,31Hz	5,81Hz	8,90Hz
10. Case	**1,57mm**	**210MPa**	**6,32Hz**	**11,0Hz**	**10,44Hz**

*only usefull stress values (no singularities due to boundary conditions etc.)

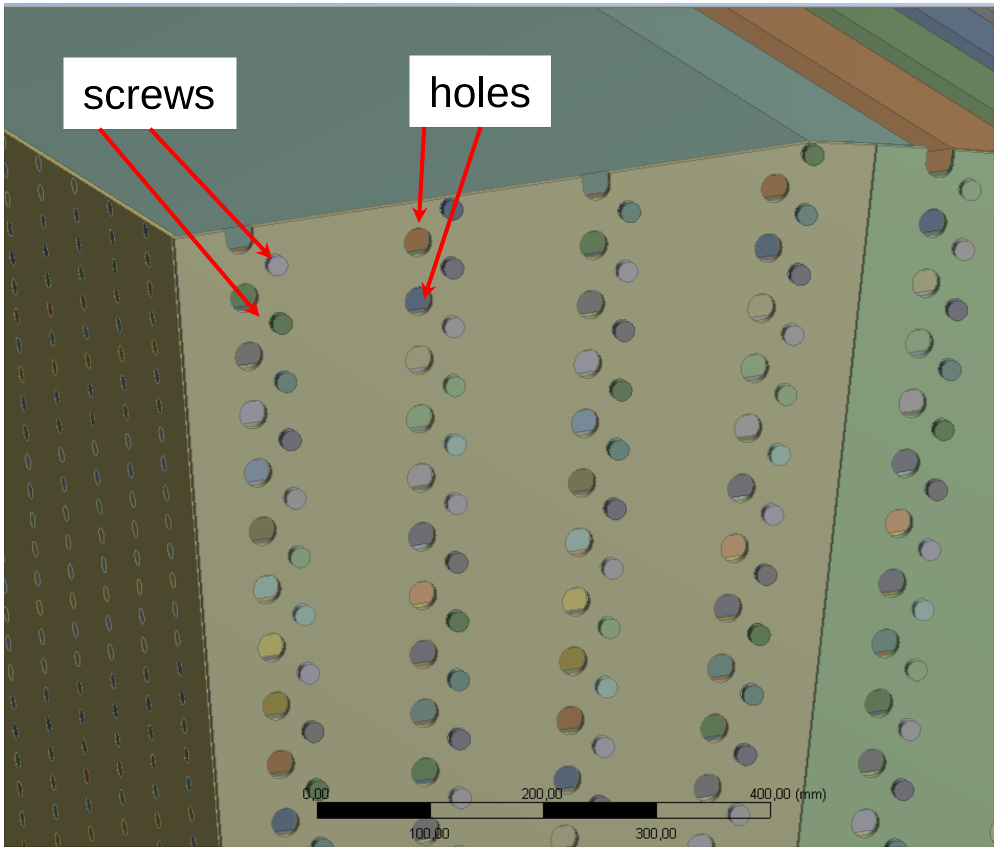
**due to the geometry, the ECAL-Mass deforms the first plate to much, this is the value for the coverplates on top

The new AHCAL Geometry in Detail – Backplate Design

> „Special Design“ of the backplates:

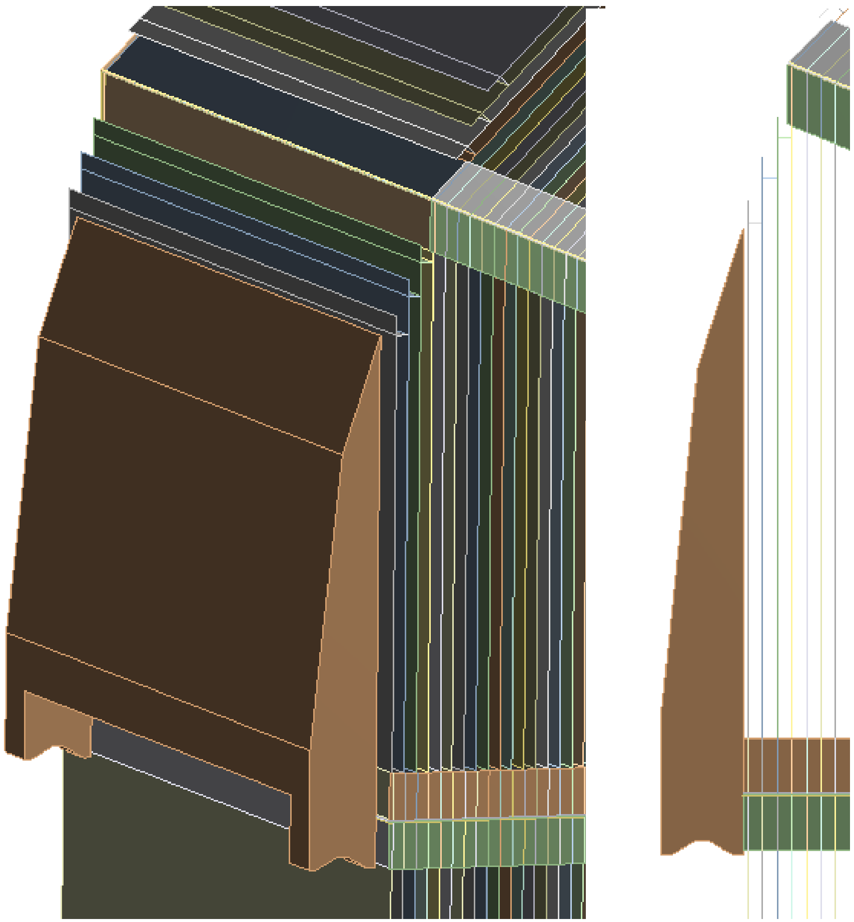
- Two AHCAL-Rings should be mounted next to each other as near as possible
- The screw heads of both AHCAL-Rings have gaps/recesses in the opposite backplate
- Therefore screws of the backplates have an offset in their arrangement
- No „crack“ for muons

  apart from tolerances

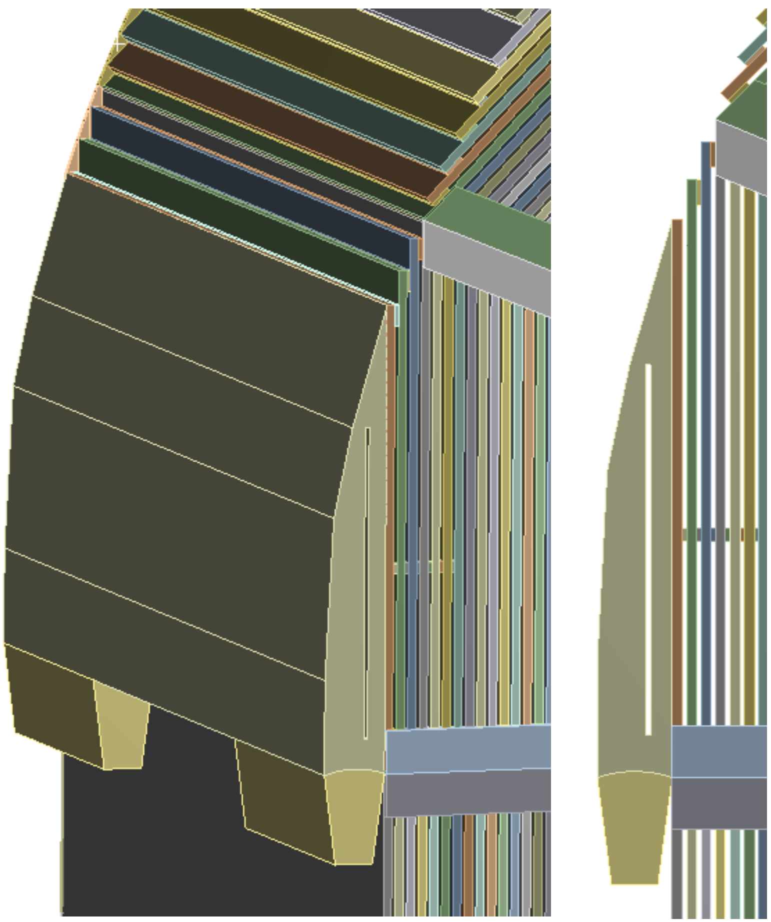


The new AHCAL Geometry in Detail – Upgrade the support structure

- Change Support geometry to enable the mounting of detector units within the support structure, the height in the additional layer is about 720mm



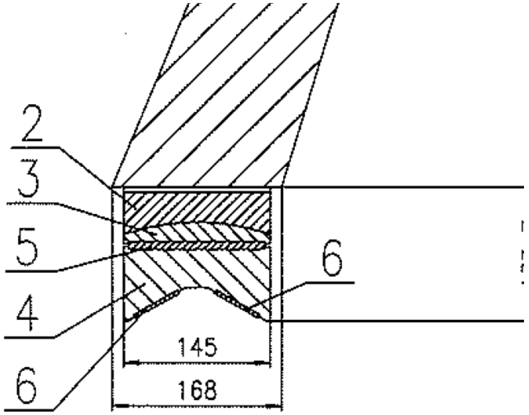
before



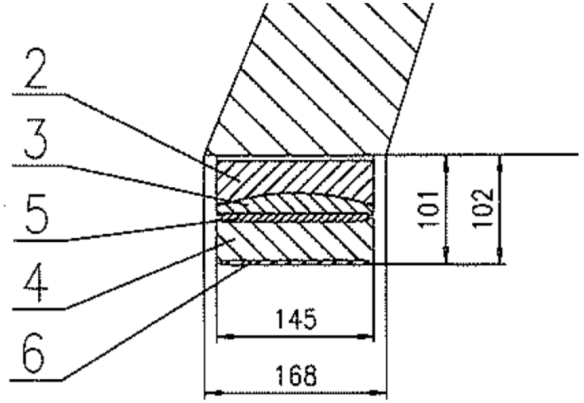
after

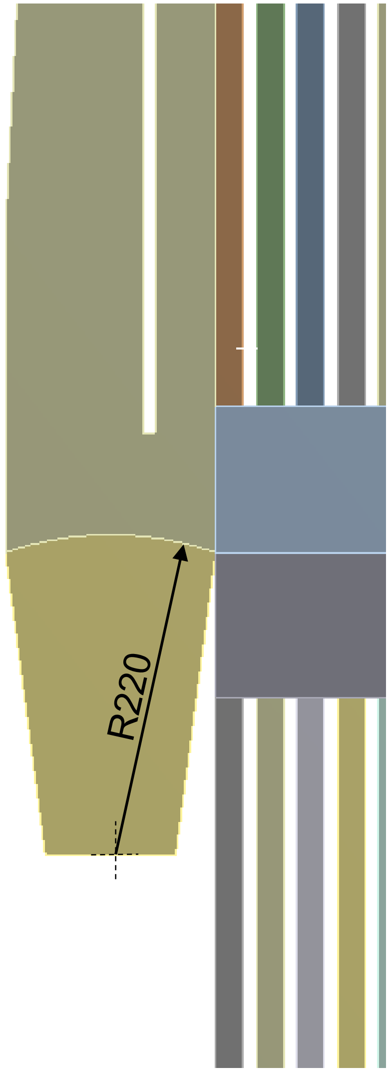
The new AHCAL Geometry in Detail – Upgrade the support structure

- Implement the real support conditions to the FE-M
- Fixed Support-Side
  - 2 => Curved steel plate
  - 3 => CFK-Support pad
  - 4 => steel prisma (linear guidance)
  - 6 => Slide plate



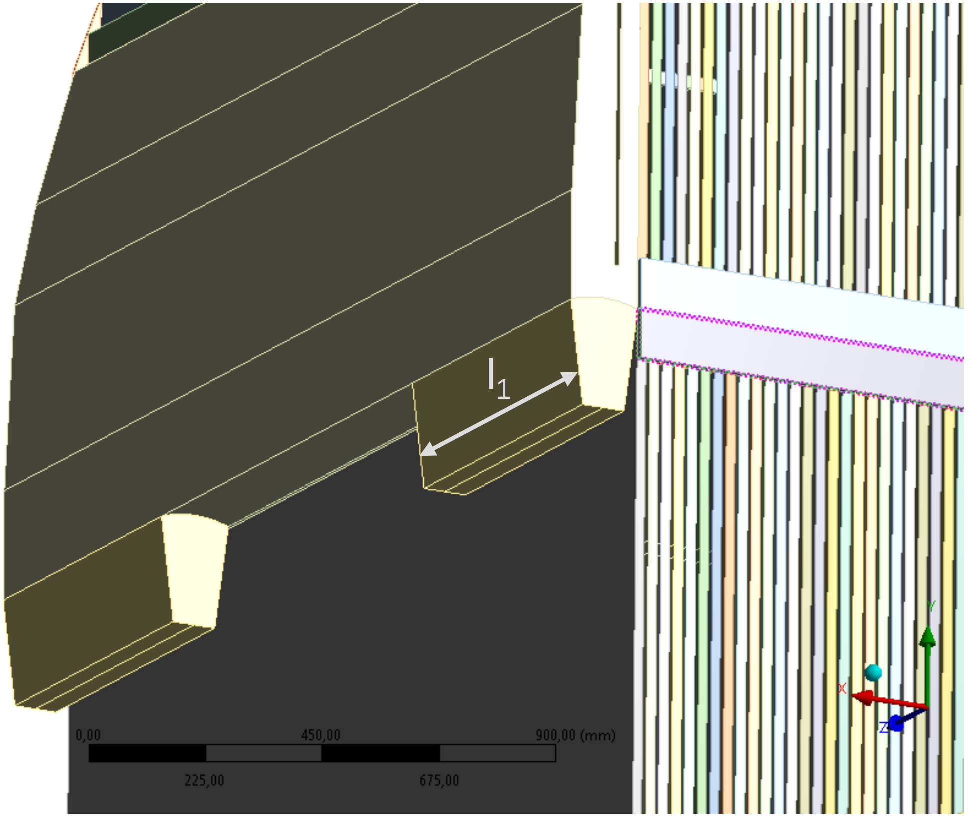
- Floating Support-Side
  - 2 => Curved steel plate
  - 3 => CFK-Support pad
  - 4 => steel plate (horizontal floating)
  - 6 => Slide plate





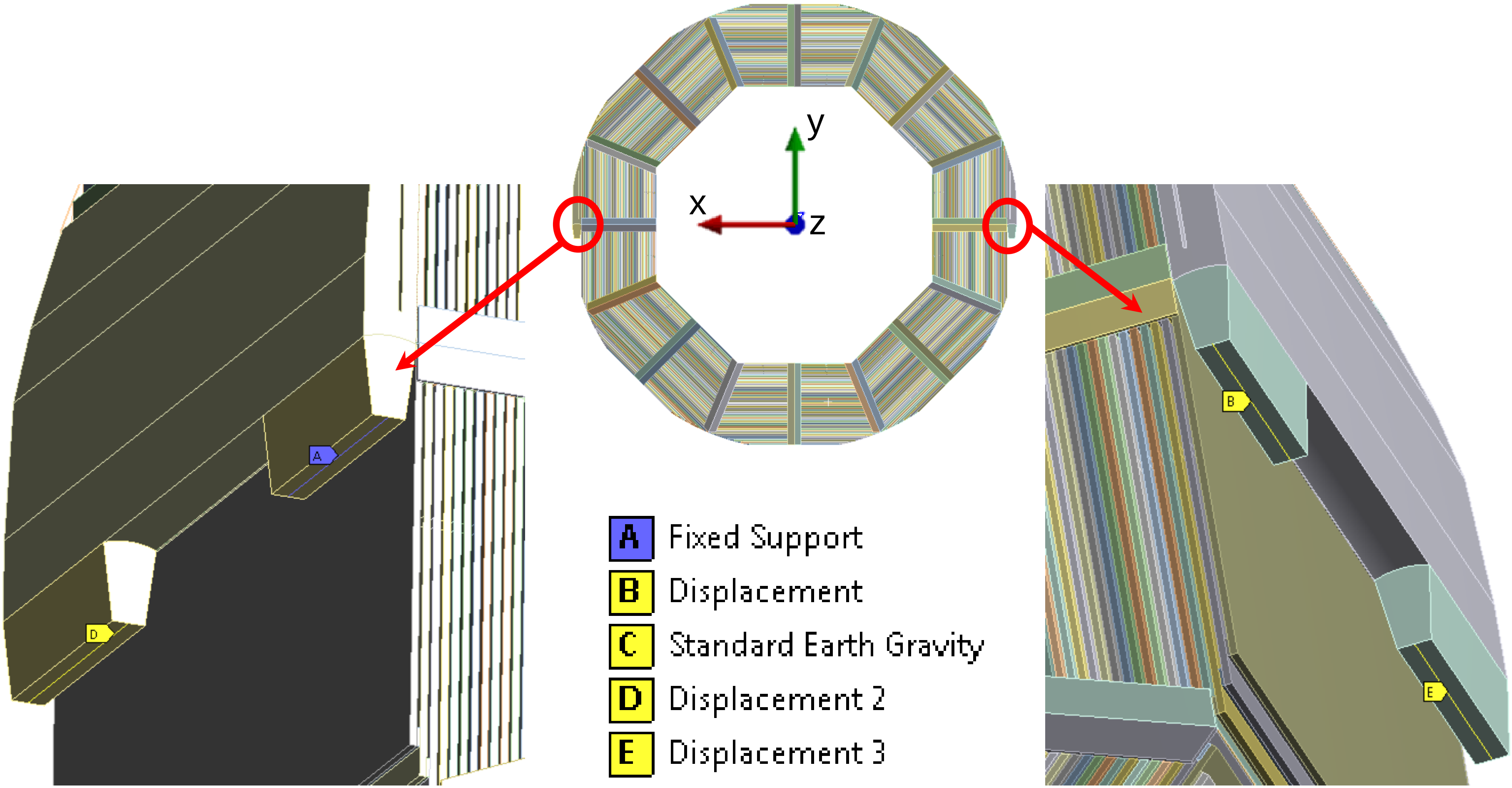
The new AHCAL Geometry in Detail – Upgrade the support structure

- The supports rest on curved CFK-plates and allows the support to rotate arround a radius about R = 220mm
- In the FE-Model an auxiliary geometry is included to define the line of rotation as boundary conditior
- The lenght/depth of this extra geometry is calculated by the following parameters:
  - Max. stress in CFK 100N/mm²
  - Safety factor (max. stress): 6x
  - Force due to the detector weight is about 1.614,63e3kN (per support side half the weight)
  - Max. amplitude in dynamic case is twice the gravitational accel.
  - **=>** Necessary lenght l_1 is 656mm



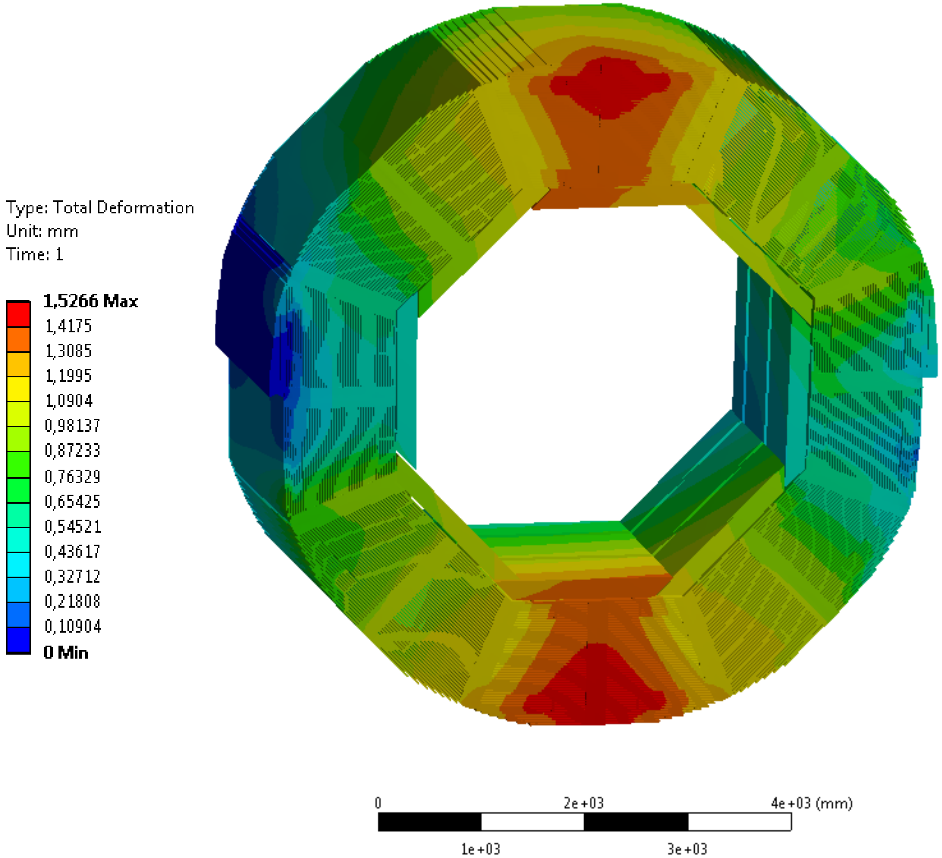
The new AHCAL Geometry in Detail – Upgrade the support structure

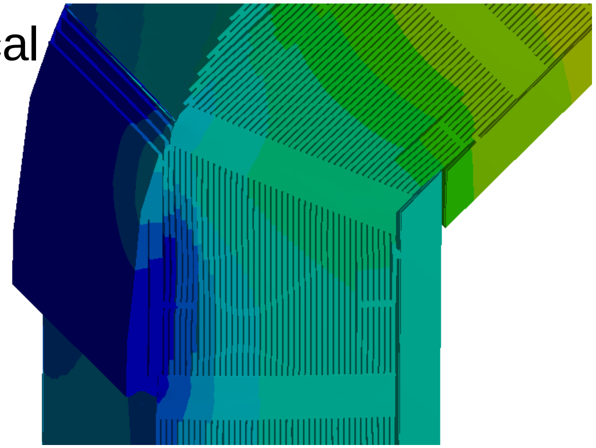
> Support boundary condition in the FE-Model

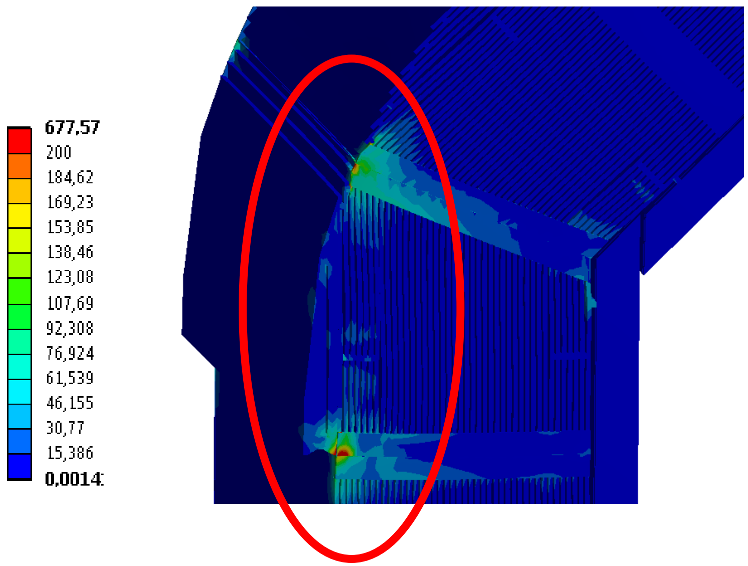


2nd Study on the reinforcements of the AHCAL – Critical Areas

- Total deformation on left, near the support some critical areas => right top corner: deformation,
  => right bottom corner: stresses (Mises)
- Structural reinforcements needed …

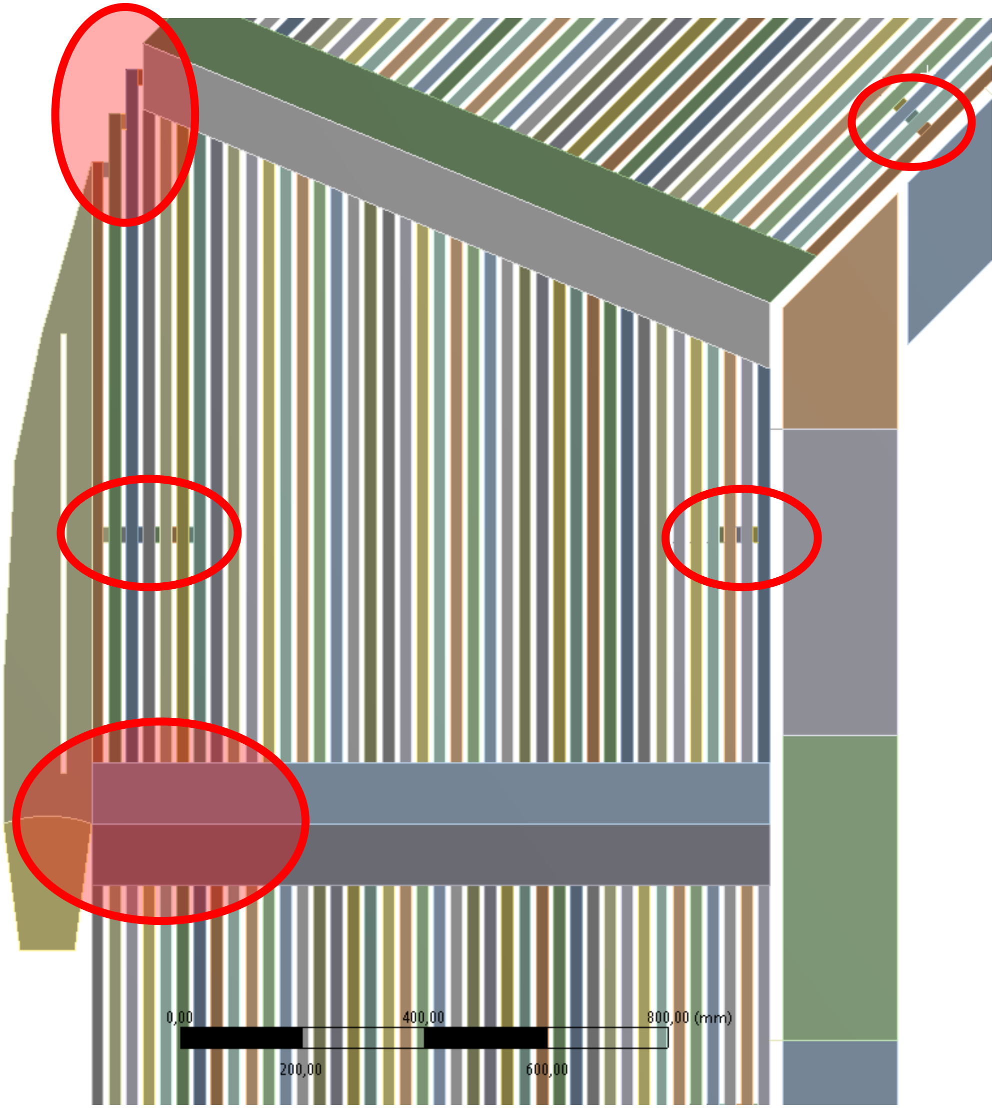






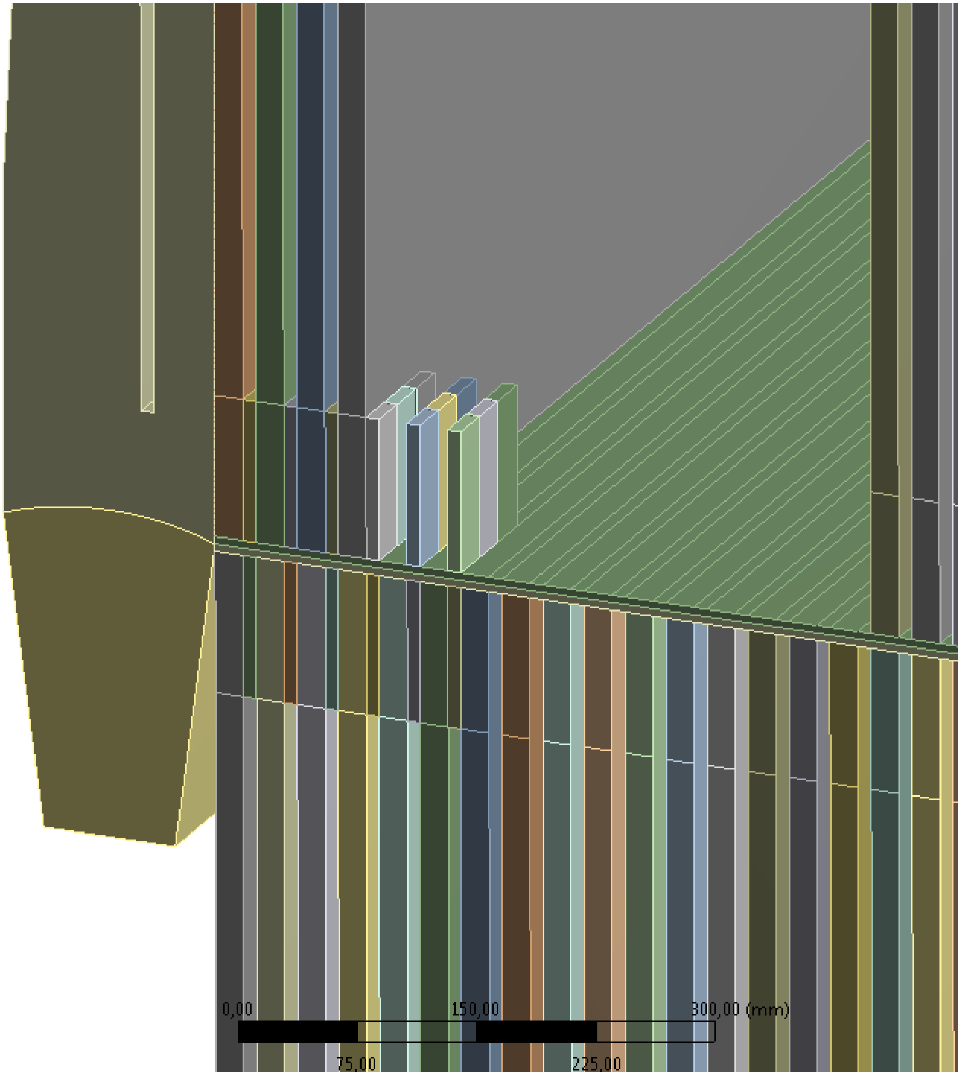
2nd Study on the reinforcements of the AHCAL

- High forces and moments in the near of the supports
- Connection between support and first plate
- In the last study additional spacer introduced
- Critical areas near the support and on top plates (ledges) needs more reinforcements
- Load through gravitational effects (vertical, 1g)



2nd Study on the reinforcements of the AHCAL

- Blocks, each 90 depth and 95mm height introduced
- Four variants investigated:
  1. **6 + 6 Blocks**
  2. 3 + 3 Blocks
  3. 3 + 0 Blocks
  4. 0 + 0 Blocks



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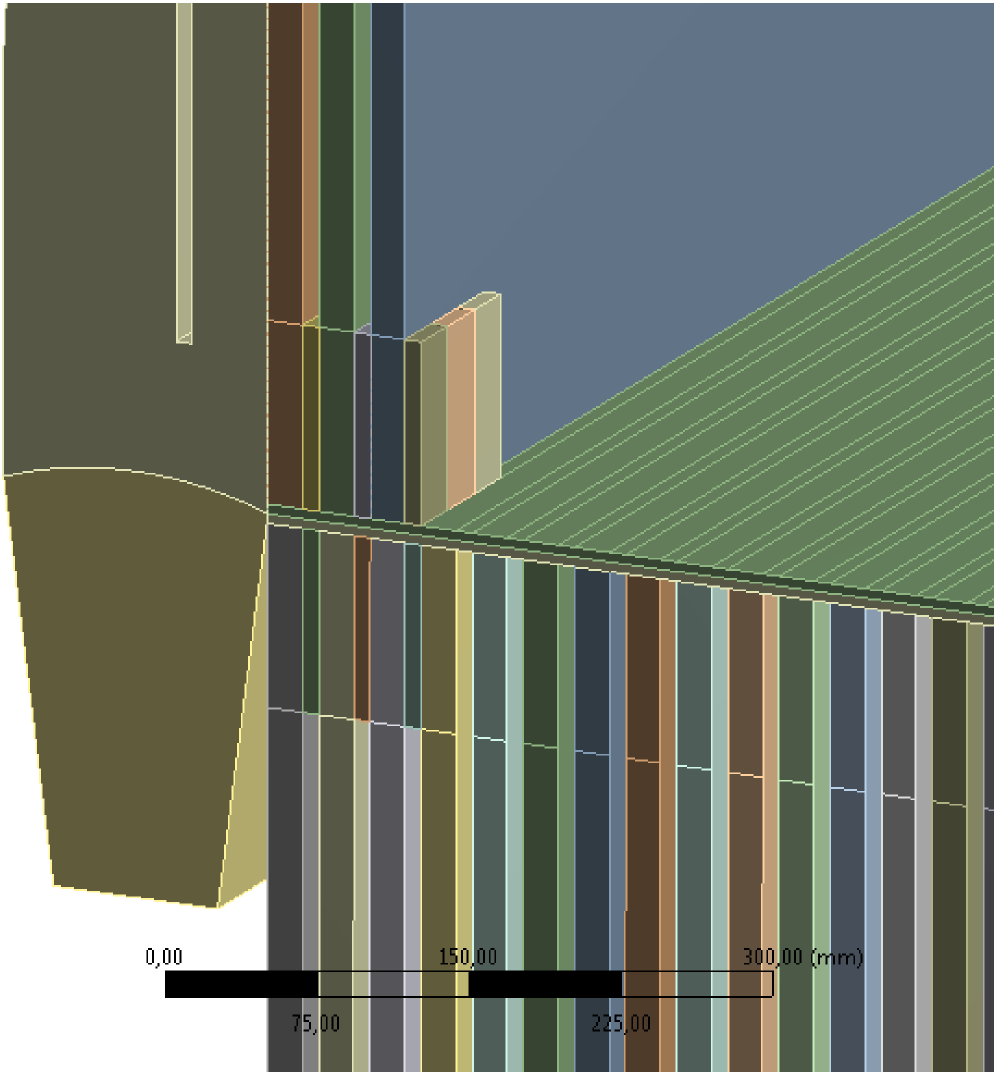

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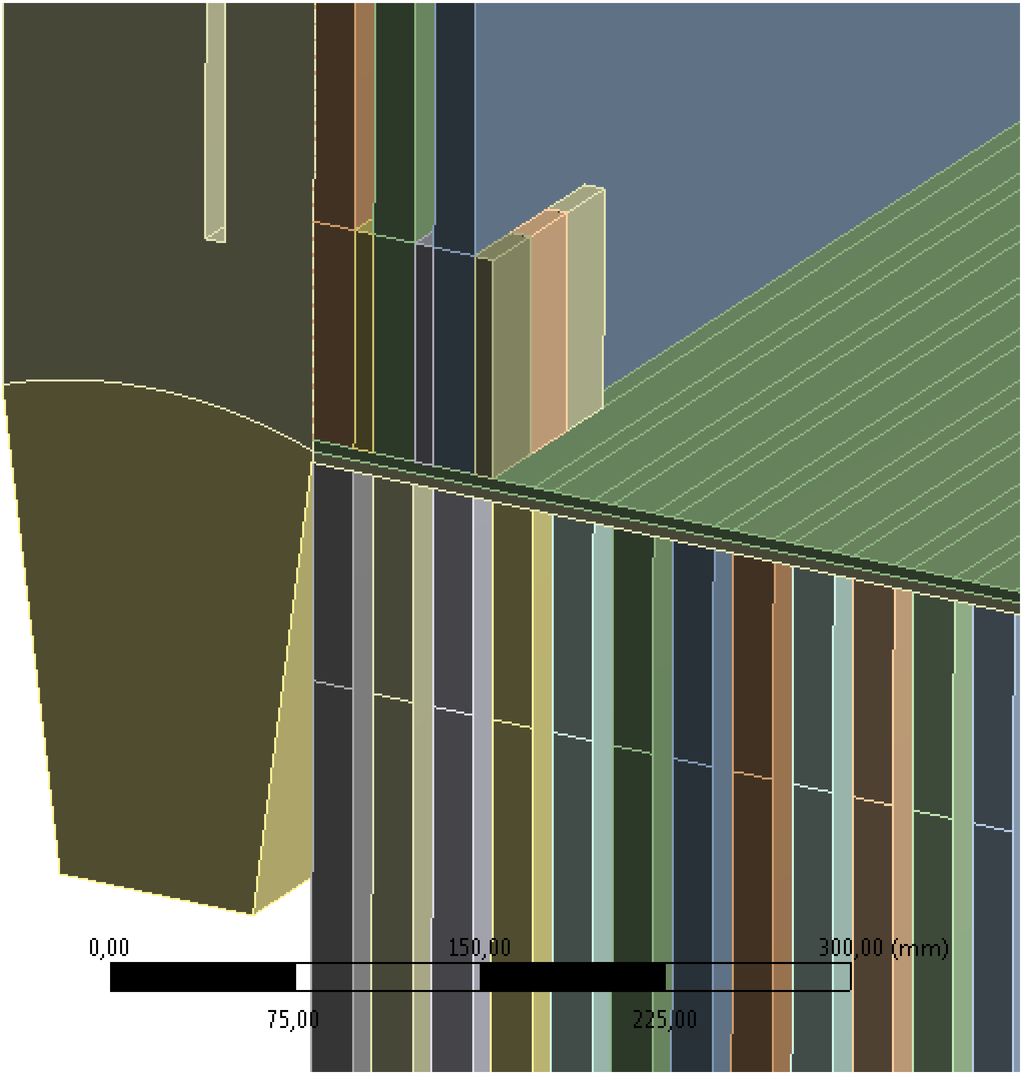

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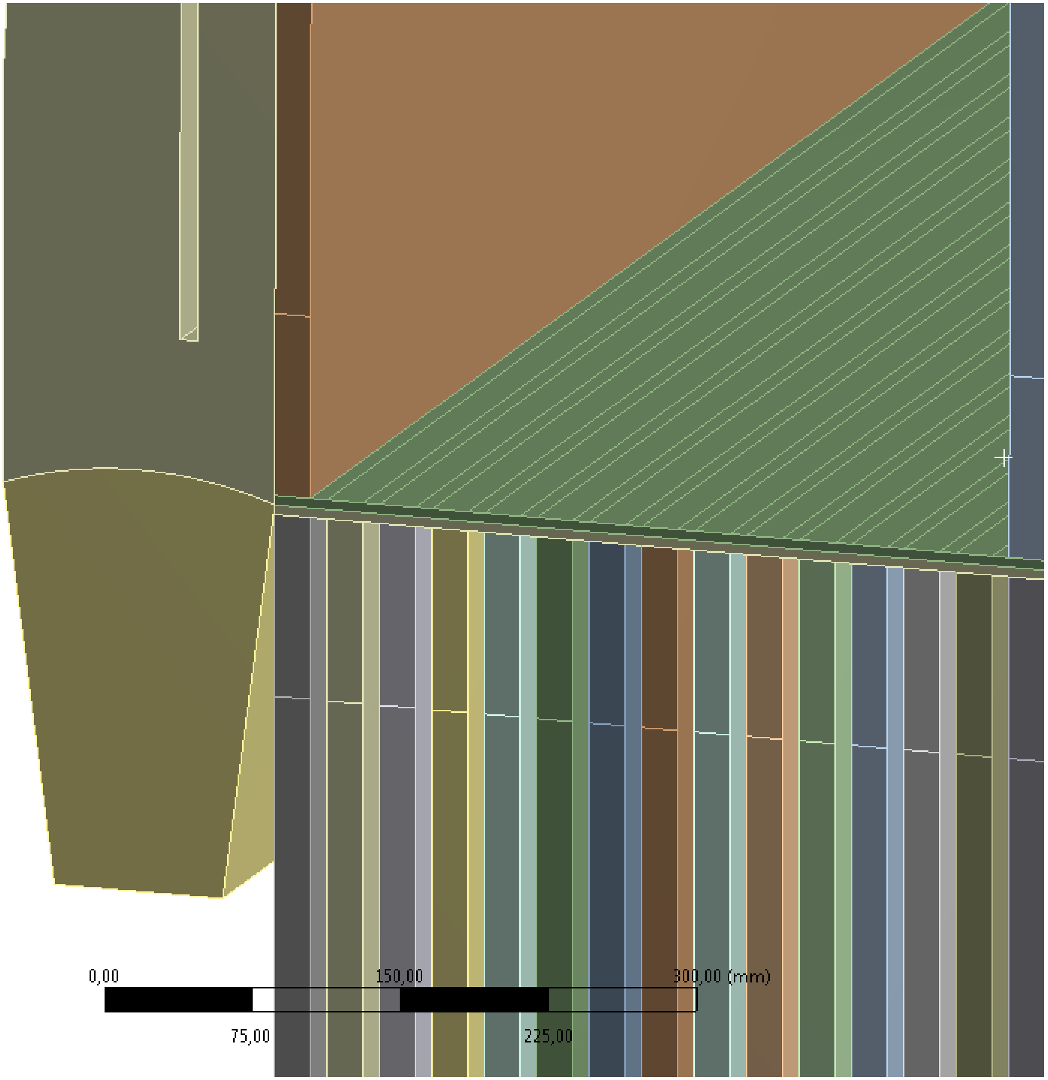
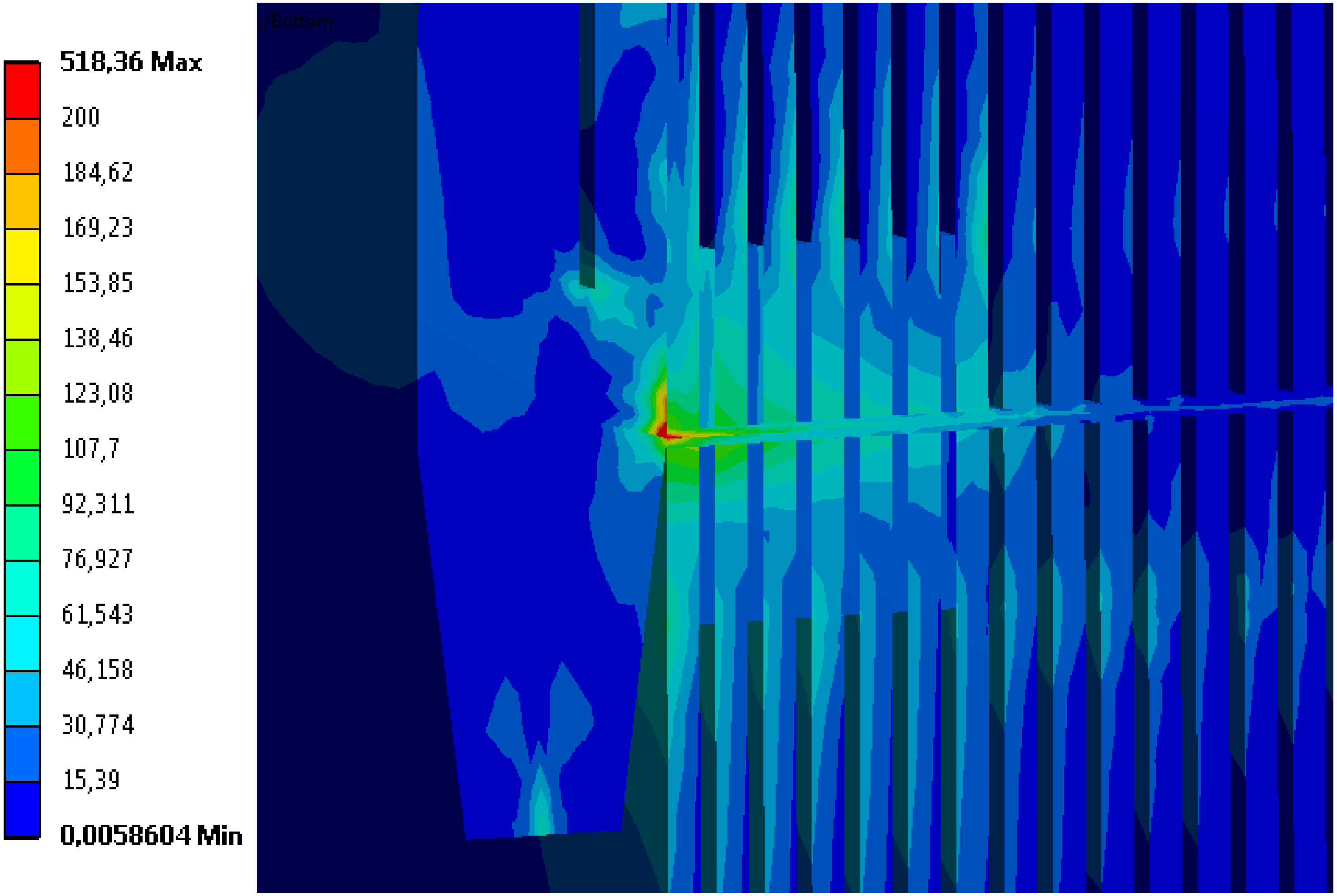


2nd Study on the reinforcements of the AHCAL

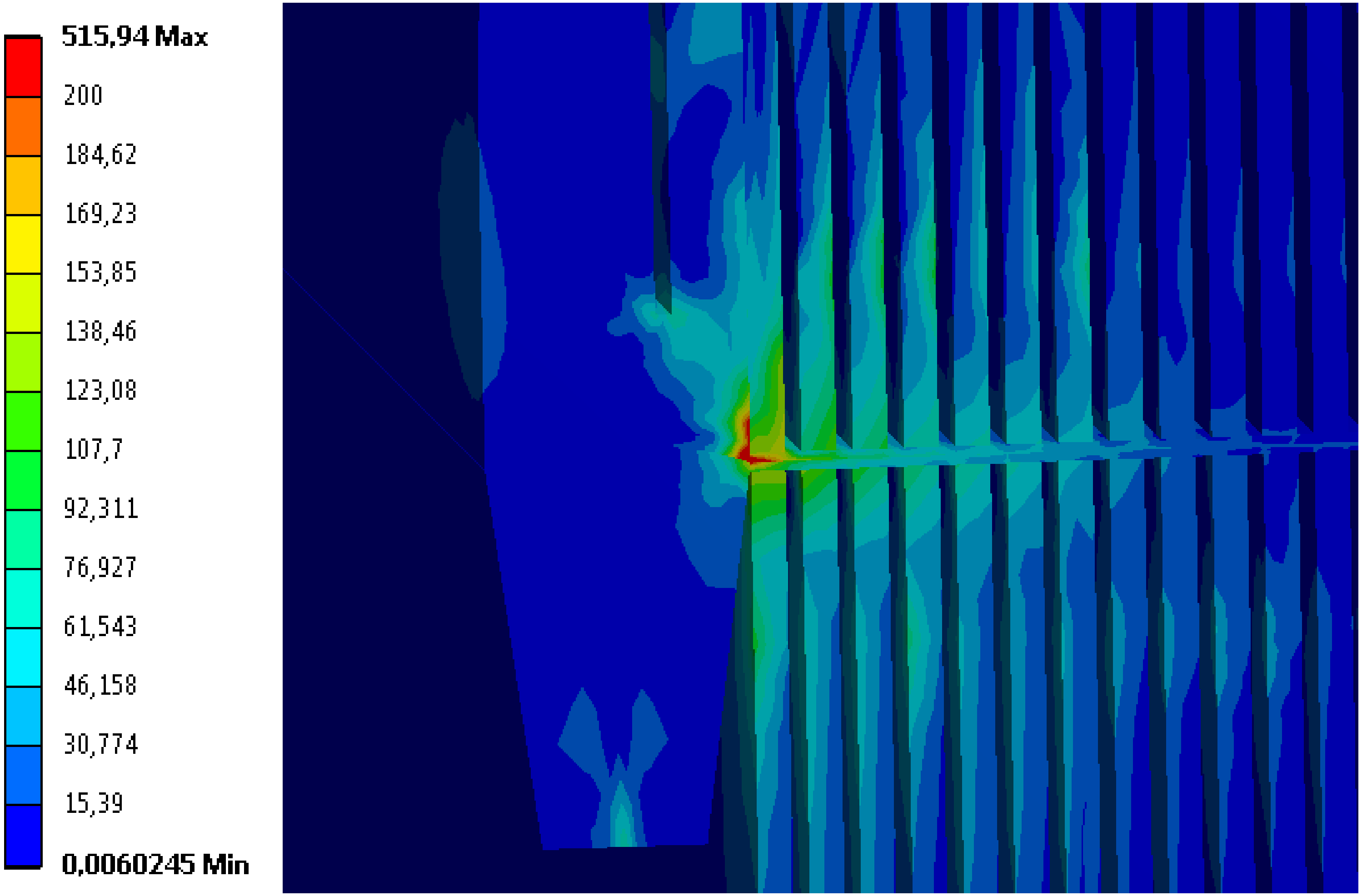
> Reduction of max. Mises-Stresses with more Blocks: **6 + 6 Blocks**



* Near support, reliable values without singularities

2nd Study on the reinforcements of the AHCAL

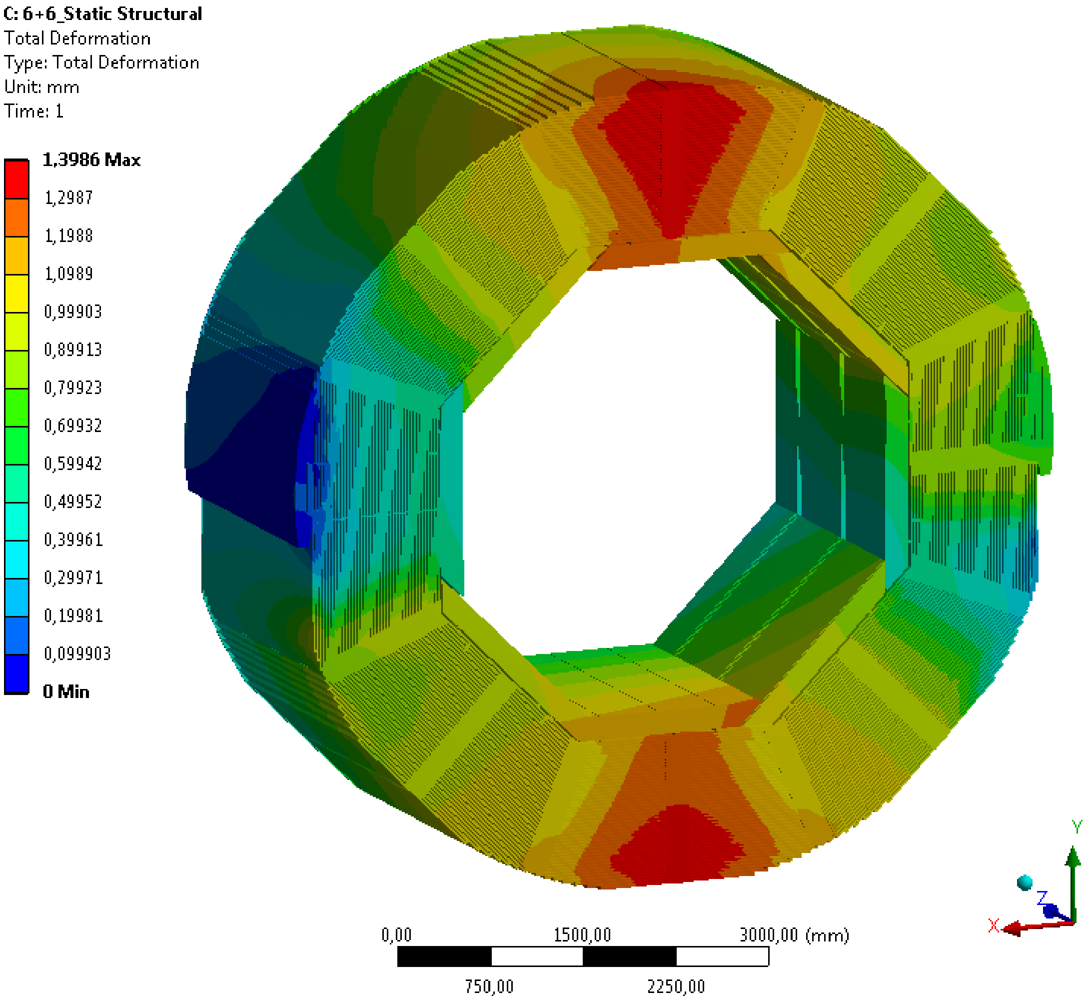
> Reduction of max. Mises-Stresses with more Blocks: **0 + 0 Blocks**



* Near support, reliable values without singularities

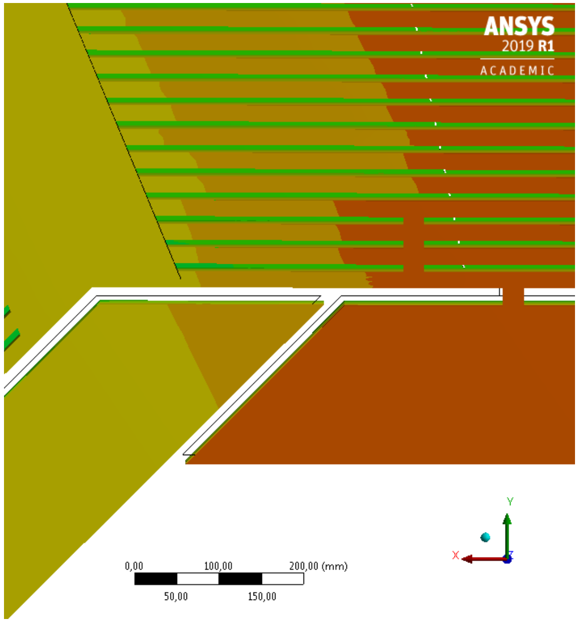
2nd Study on the reinforcements of the AHCAL

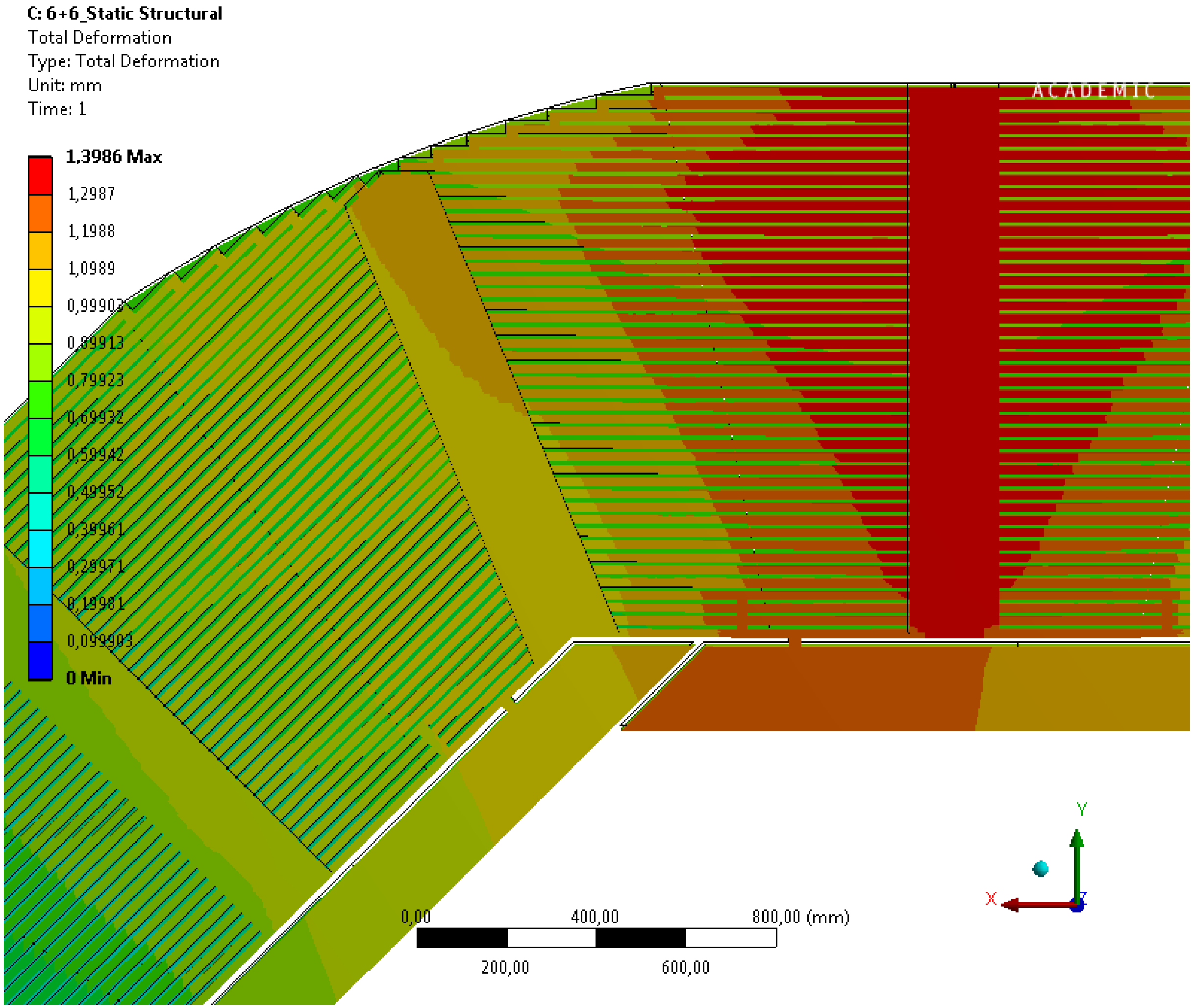
- Total deformation of the 6 + 6 case (1,40mm)



2nd Study on the reinforcements of the AHCAL

- Total deformation detail on ECAL (undeformed wireframe shown, 10x Scale Factor)





2^{nd} Study on the reinforcements of the AHCAL

- Reduction of Stress, better load distribution into the AHCAL-Structure
- Small impact on deformation respectively the Eigenmodes, no real differences observed
- Further analyses with additional loads in all three directions to estimate the dynamic behaviour
- Choosen case: 6 + 6 (best stress distribution near the supports)

	Max. Deform.	Max. Equ. Stress*	1. Mode	2. Mode	3. Mode
6 + 6	**1,40mm**	**105MPa**	**5,52Hz**	**11,27Hz**	**11,44Hz**
3 + 3	1,40mm	110MPa	5,52Hz	11,27Hz	11,43Hz
3 + 0	1,41mm	125MPa	5,51Hz	11,26Hz	11,42Hz
0 + 0	1,42mm	135MPa	5,51Hz	11,25Hz	11,40Hz

* Near support, reliable values without singularities

Estimate the dynamical behaviour

- Additional load cases of the 6 + 6 case

  1. 2x 9,81 m/sec² in vertical direction (y-axis)
  2. 1x 9,81 m/sec² vertical and 1x 9,81 m/sec² in positive horizontal direction (x-axis)
  3. 1x 9,81 m/sec² vertical and 1x 9,81 m/sec² in negative horizontal direction (x-axis)
  4. 1x 9,81 m/sec² vertical and 1x 9,81 m/sec² in positive longitudinal direction (z-axis)
  5. 1x 9,81 m/sec² vertical and 1x 9,81 m/sec² in negative longitudinal direction (z-axis)

- The acceleration values are **conservative** compared to the earthquake load (double the max. accelerration amplitudes compared to the Ichinoseki Earthquake from 11th March 2011)

Deformation under conservative / double earthquake loads

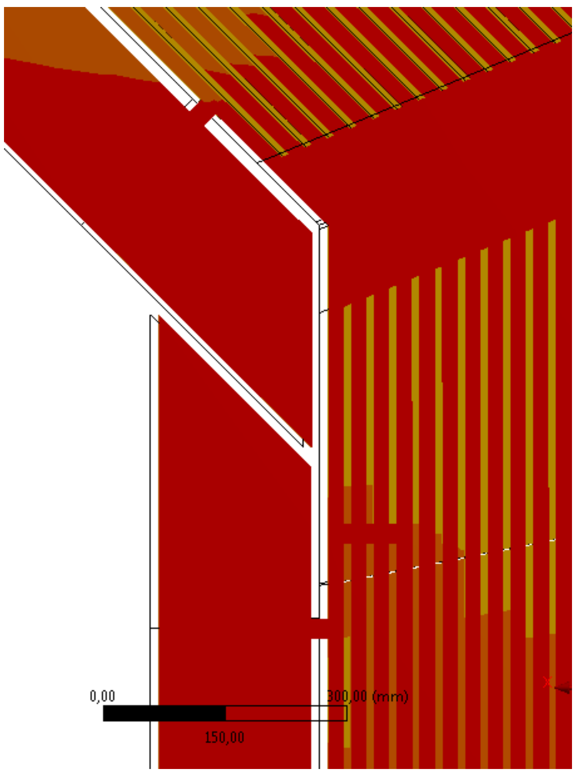
> Additional load cases to estimate the dynamical behaviour of the 6 + 6 case:

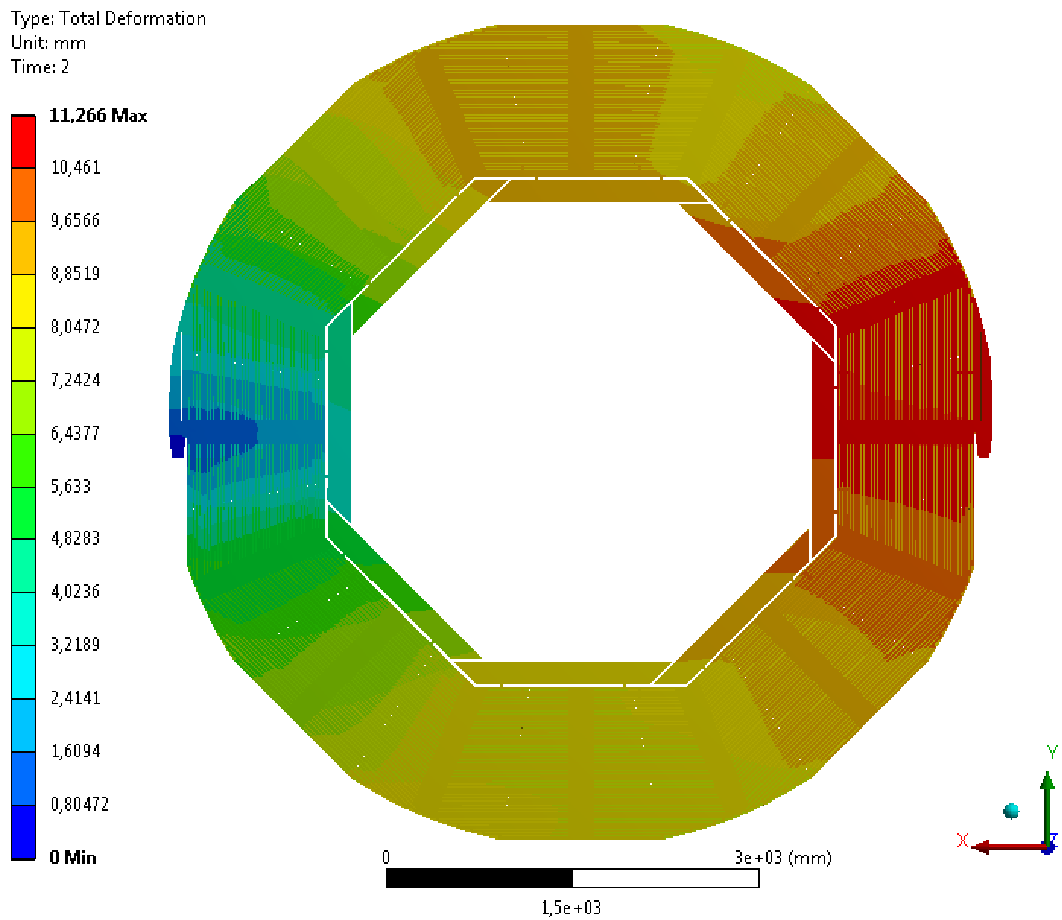
1. 1x 9,81 m/sec² and additional **1x 9,81 m/sec²** in vertical direction (y-axis)
2. 1x 9,81 m/sec² vertical and **1x 9,81 m/sec²** in positive horizontal direction (x-axis)
3. 1x 9,81 m/sec² vertical and **1x 9,81 m/sec²** in negative horizontal direction (x-axis)
4. 1x 9,81 m/sec² vertical and **1x 9,81 m/sec²** in positive longitudinal direction (z-axis)
5. 1x 9,81 m/sec² vertical and **1x 9,81 m/sec²** in negative longitudinal direction (z-axis)

Load Case	Max. Deform.	Max. Equ. Stress*	Deform. x-Direction	Deform. y-Direction	Deform. z-Direction
0	1,39mm	180N/mm²	0,96mm	1,25mm	0,62mm
1	2,77mm	410N/mm²	1,93mm	2,50mm	1,23mm
2	11,26mm	250N/mm²	11,26mm	5,14mm	1,79mm
3	10,22mm	160N/mm²	10,21mm	3,87mm	2,43mm
4	3,85mm	260N/mm²	3,63mm	2,72mm	2,87mm
5	4,20mm	160N/mm²	2,81mm	2,81mm	3,37mm

Worst case

- Total deformation from 2. load case (1g vertical, 1g pos. x-direction)
- 11,27mm (scale value 1x)
- No collision detected!





Deformation under earthquake-like loads

- Additional load cases to estimate the dynamical behaviour of the 6 + 6 case:
  1. 1x 9,81 m/sec² and additional **0,5x 9,81 m/sec²** in vertical direction (y-axis)
  2. 1x 9,81 m/sec² vertical and **0,5x 9,81 m/sec²** in positive horizontal direction (x-axis)
  3. 1x 9,81 m/sec² vertical and **0,5x 9,81 m/sec²** in negative horizontal direction (x-axis)
  4. 1x 9,81 m/sec² vertical and **0,5x 9,81 m/sec²** in positive longitudinal direction (z-axis)
  5. 1x 9,81 m/sec² vertical and **0,5x 9,81 m/sec²** in negative longitudinal direction (z-axis)

Load Case	Max. Deform.	Max. Equ. Stress*	Deform. x-Direction	Deform. y-Direction	Deform. z-Direction
0	1,37mm	155N/mm²	0,96mm	1,20mm	0,62mm
1	2,06mm	210N/mm²	1,44mm	1,80mm	0,93mm
2	5,96mm	220N/mm²	5,95mm	3,07mm	1,16mm
3	5,07mm	125N/mm²	5,06mm	2,45mm	1,06mm
4	2,50mm	80N/mm²	2,24mm	1,91mm	1,47mm
5	2,63mm	205N/mm²	1,47mm	1,94mm	1,80mm

New Support – Deformation under conservative / double earthquake loads

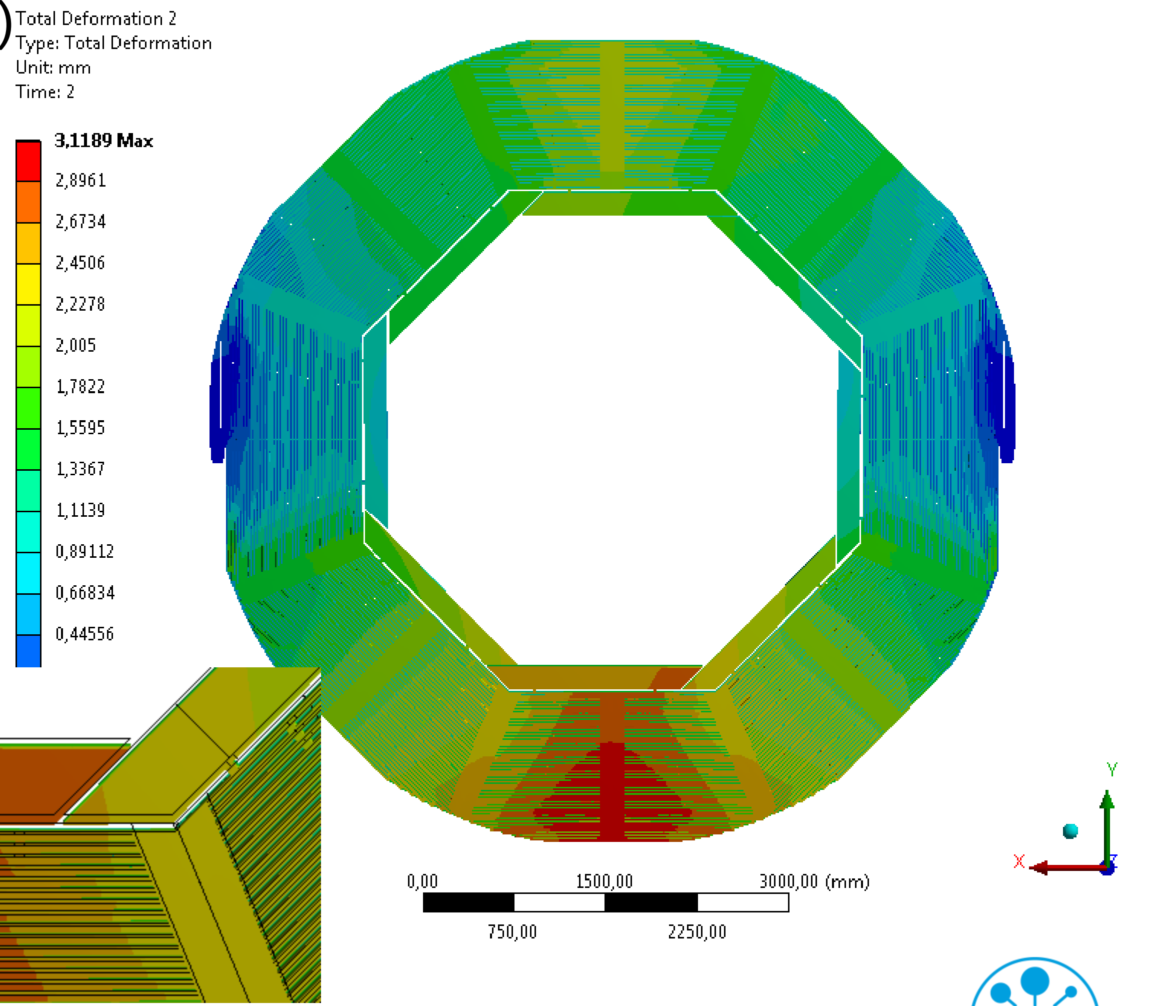
- Additional load cases to estimate the dynamical behaviour of the 6 + 6 case **with new** support definition (sliding with own weight, afterwards fixed support):

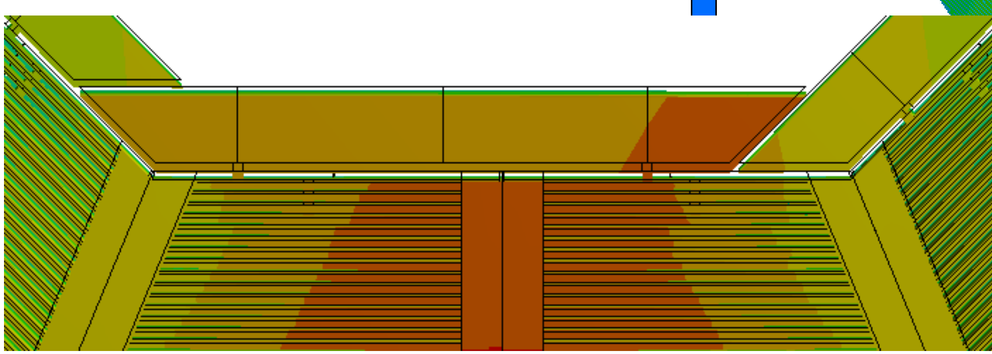
1. 1x 9,81 m/sec² and additional **1x 9,81 m/sec²** in vertical direction (y-axis)
2. 1x 9,81 m/sec² vertical and **1x 9,81 m/sec²** in positive horizontal direction (x-axis)
3. 1x 9,81 m/sec² vertical and **1x 9,81 m/sec²** in negative horizontal direction (x-axis)
4. 1x 9,81 m/sec² vertical and **1x 9,81 m/sec²** in positive longitudinal direction (z-axis)
5. 1x 9,81 m/sec² vertical and **1x 9,81 m/sec²** in negative longitudinal direction (z-axis)

Load Case	Max. Deform.	Max. Equ. Stress*	Deform. x-Direction	Deform. y-Direction	Deform. z-Direction
0	1,39mm	140N/mm²	0,97mm	1,21mm	0,62mm
1	3,12mm	220N/mm²	1,63mm	2,73mm	1,52mm
2	3,73mm	175N/mm²	3,27mm	1,80mm	0,96mm
3	3,69mm	195N/mm²	3,24mm	1,60mm	0,92mm
4	2,66mm	175N/mm²	1,54mm	1,80mm	2,00mm
5	3,75mm	300N/mm²	1,95mm	2,48mm	2,86mm

Worst case

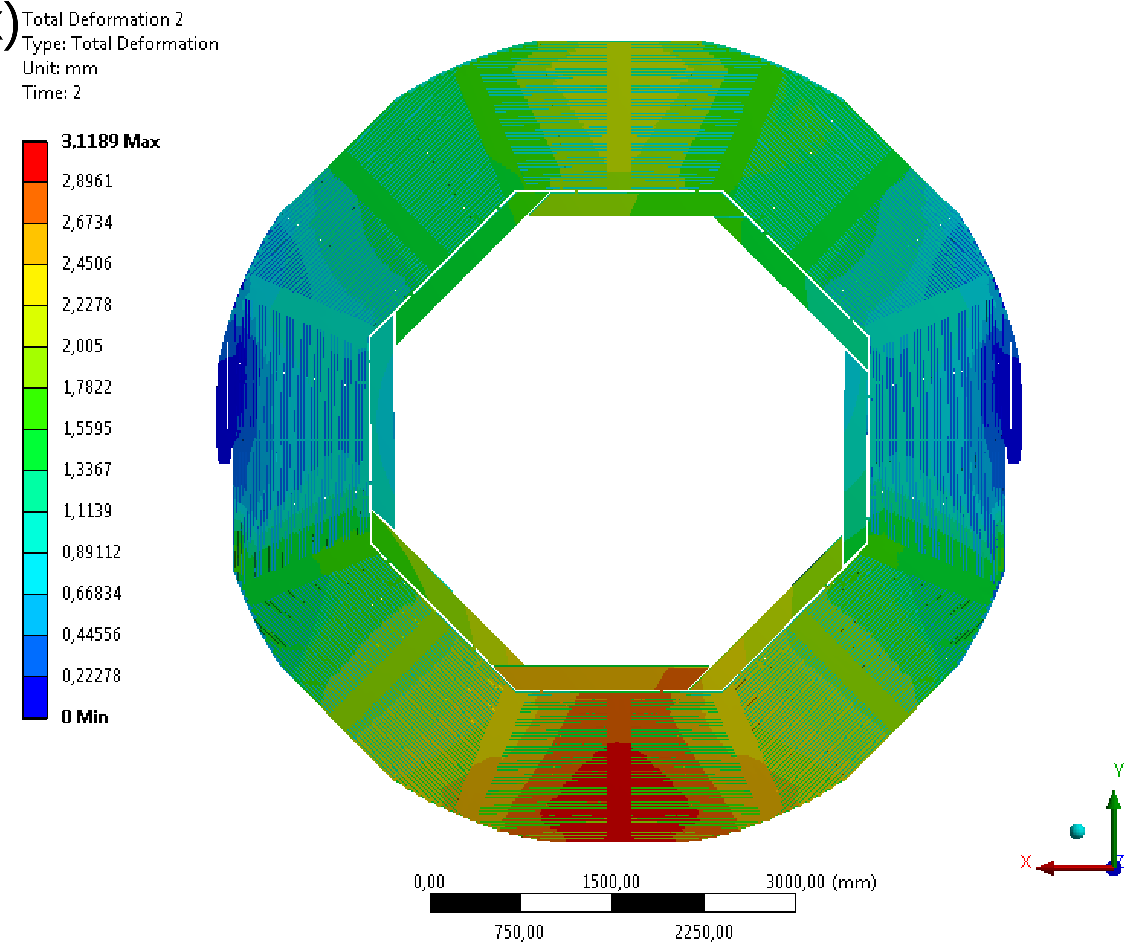
- Total deformation from 2. load case (1g vertical, 1g pos. x-direction)
- 3,27mm (scale value 10x)
- No collision detected!

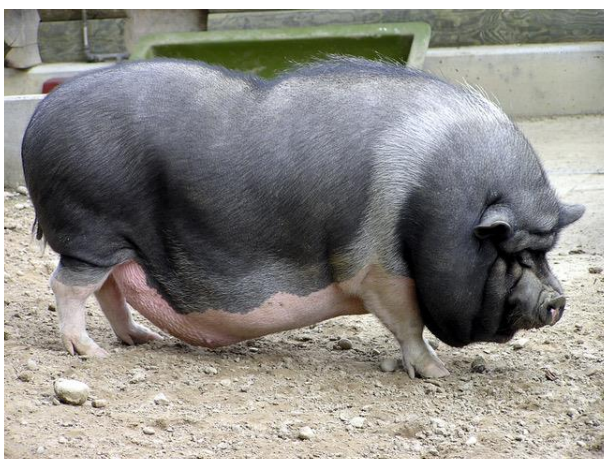




Worst case

- Total deformation from 2. load case (1g vertical, 1g pos. x-direction)
- 3,27mm (scale value 10x)
- No collision detected!





New Support – Deformation under earthquake-like loads

- Additional load cases to estimate the dynamical behaviour of the 6 + 6 case with new support definition (sliding with own weight, afterwards fixed support):

1. 1x 9,81 m/sec² and additional **0,5x 9,81 m/sec²** in vertical direction (y-axis)
2. 1x 9,81 m/sec² vertical and **0,5x 9,81 m/sec²** in positive horizontal direction (x-axis)
3. 1x 9,81 m/sec² vertical and **0,5x 9,81 m/sec²** in negative horizontal direction (x-axis)
4. 1x 9,81 m/sec² vertical and **0,5x 9,81 m/sec²** in positive longitudinal direction (z-axis)
5. 1x 9,81 m/sec² vertical and **0,5x 9,81 m/sec²** in negative longitudinal direction (z-axis)

Load Case	Max. Deform.	Max. Equ. Stress*	Deform. x-Direction	Deform. y-Direction	Deform. z-Direction
0	1,39mm	140N/mm²	0,97mm	1,21mm	0,62mm
1	2,34mm	185N/mm²	1,22mm	2,04mm	1,14mm
2	2,28mm	100N/mm²	2,00mm	1,50mm	0,84mm
3	2,26mm	170N/mm²	1,96mm	1,40mm	0,82mm
4	1,84mm	140N/mm²	0,93mm	1,36mm	1,24mm
5	2,62mm	245N/mm²	1,38mm	1,90mm	1,81mm

New Support – Modal Results

- The New Support stiffens the ACHAL Structure
- The first eigenfrequency ist increased by 75%
- This example exclude the influences of the surrounding structures (cryostat stiffness, support of the cryostat in the Barrel Strucutre, etc.)

	Max. Deform.	Max. Equ. Stress*	1. Mode	2. Mode	3. Mode
6 + 6	1,39mm	140N/mm²	9,63Hz	11,36Hz	13,54Hz

* Near support, reliable values without singularities

Summary

- Reinforcements in critical points to optimise rigidity
- Optimisation of spacer layout in respect of the placement of the detector modules for the AHCAL
- Backplates at centre of barrel (z=0) cover full end face and improve rigidity considerably
- One active layer with 720mm height in support
- Residual static displacements could be compensated by adjusting fixture for ECAL rails after survey
- Maximal displacement now below 2 mm
- Compare: CMS barrel HCAL 2-3 **%**

Next Steps

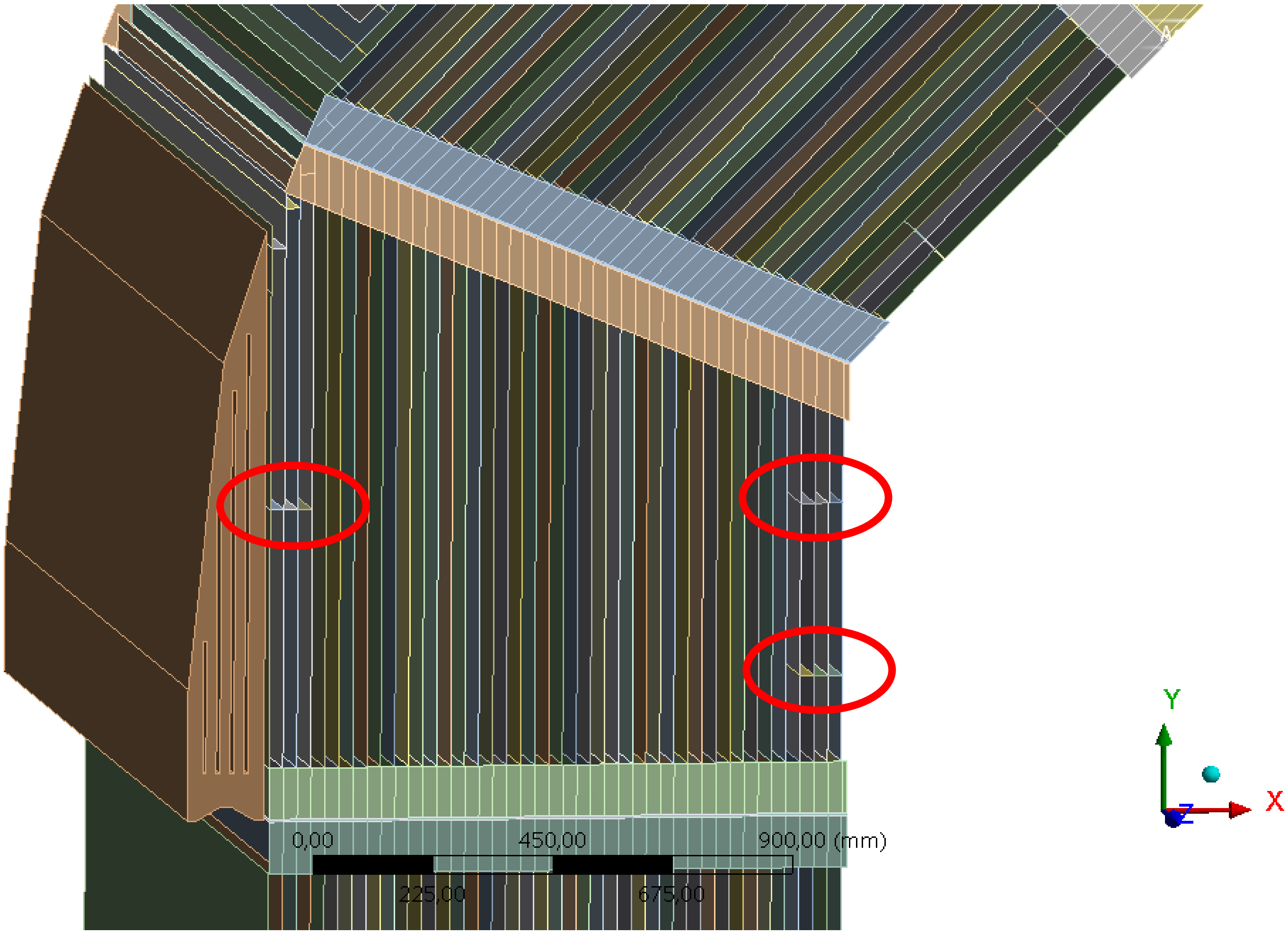
- Switch to CMS method and check for dynamic stability under realistic earthquake excitation
- Re-inforce potential critical points in dynamical behaviour
- Detailed studies on connecting elements (Coverplates, Backplates, Ledges, etc.) and screws of the AHCAL-Structure
- Common optimisation with ECAL Group

Thank you for your attention.
Any questions?

Backup Slides

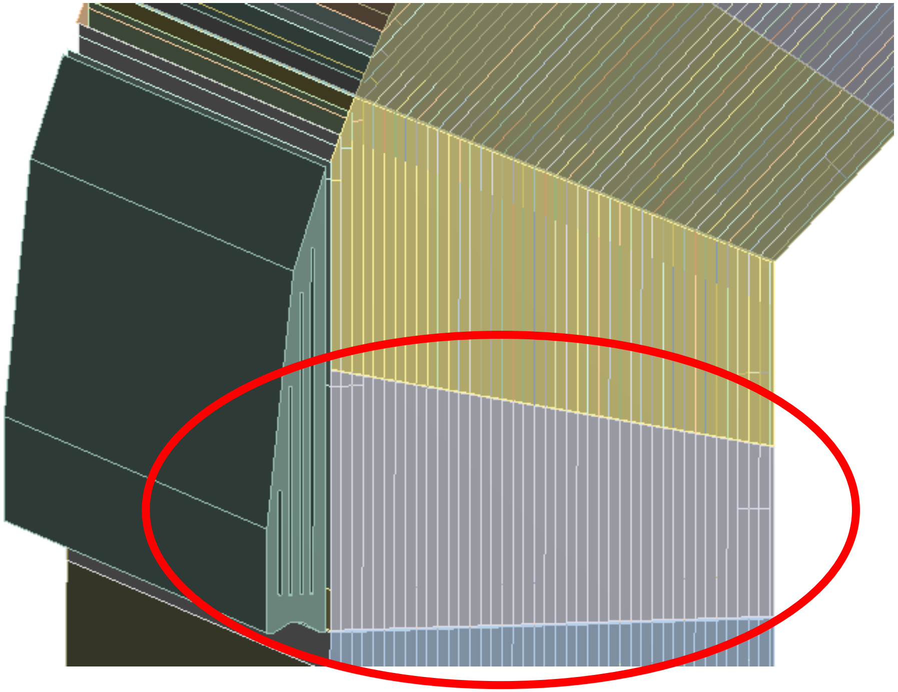
Case 2 – Geometry

- As Case 1, with Spacer on inner and outer radius (across three layer)

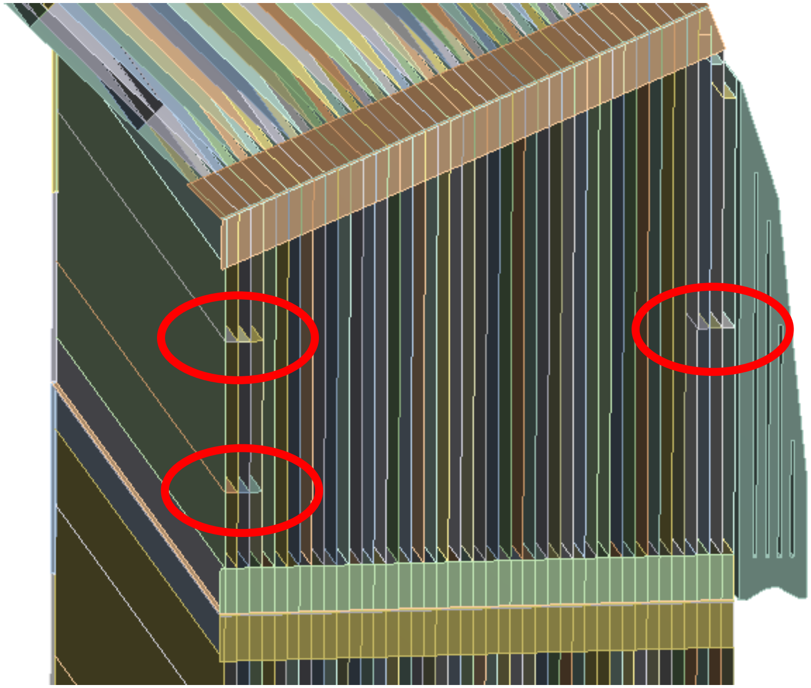


Case 3 – Geometry

- As Case 2, Back: Large plate (10mm thickness), assymmetric



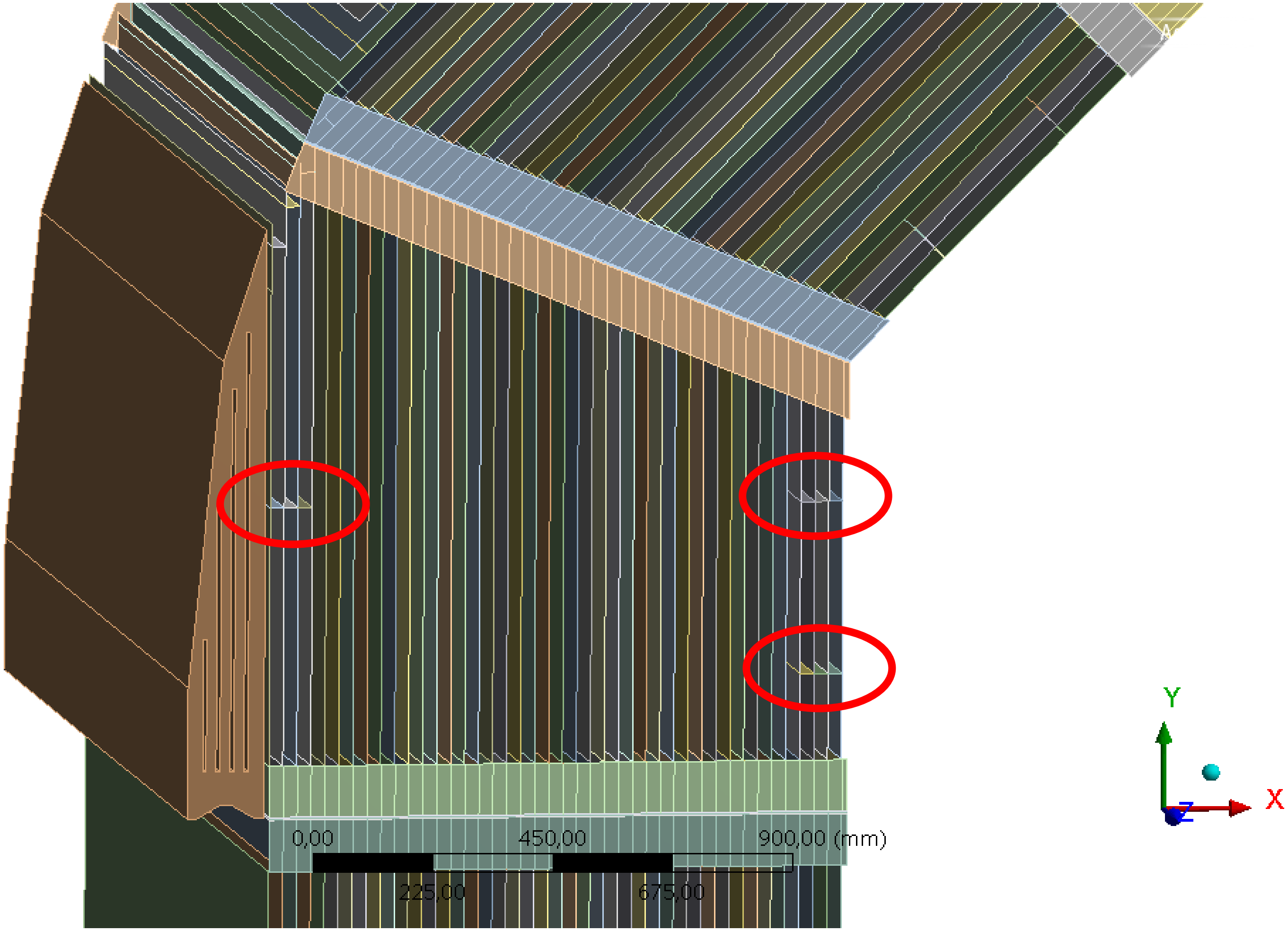
backside



front

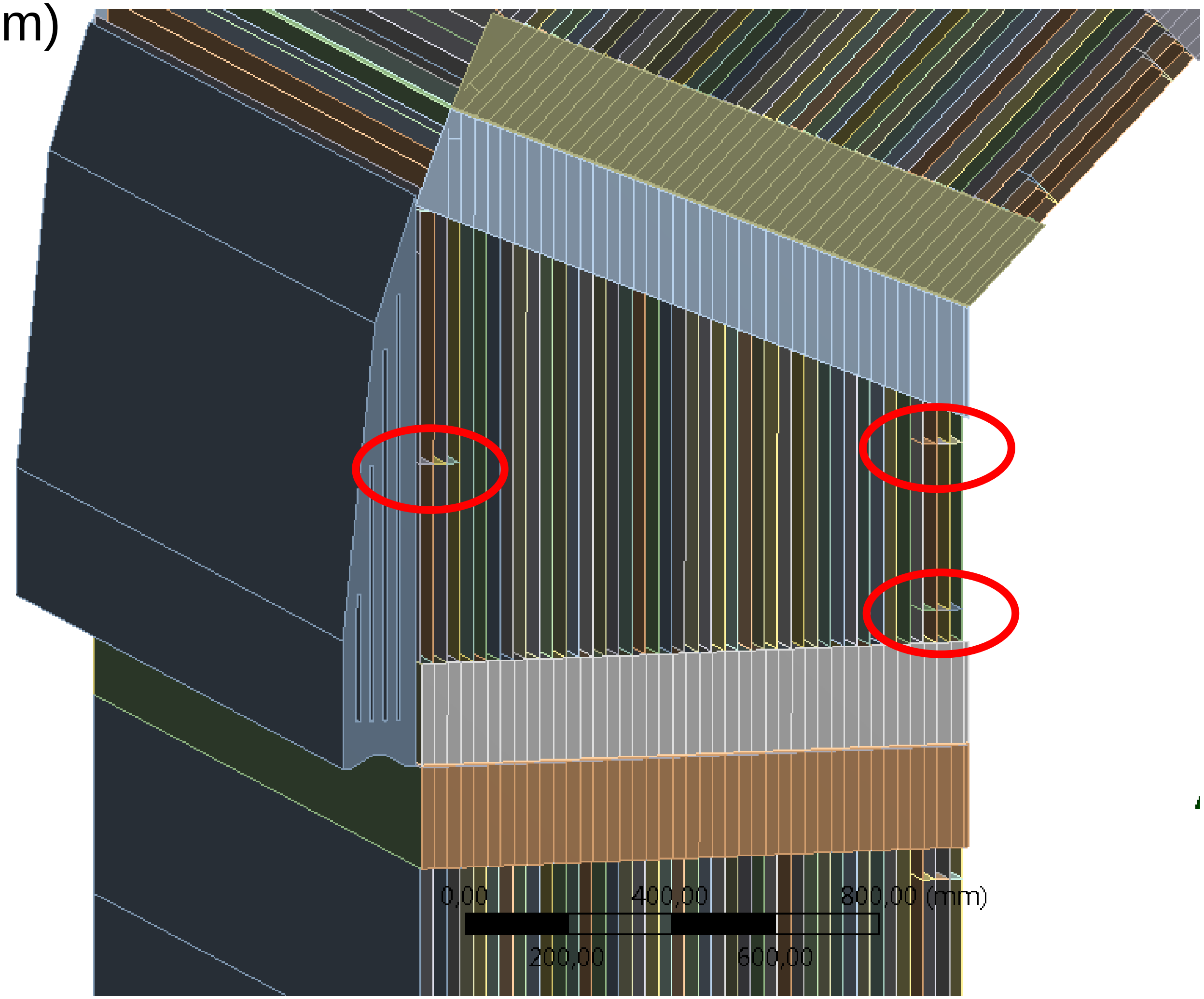
Case 4 – Geometry

- As Case 2, coverplates with double thickness (t=30mm, w=200mm)



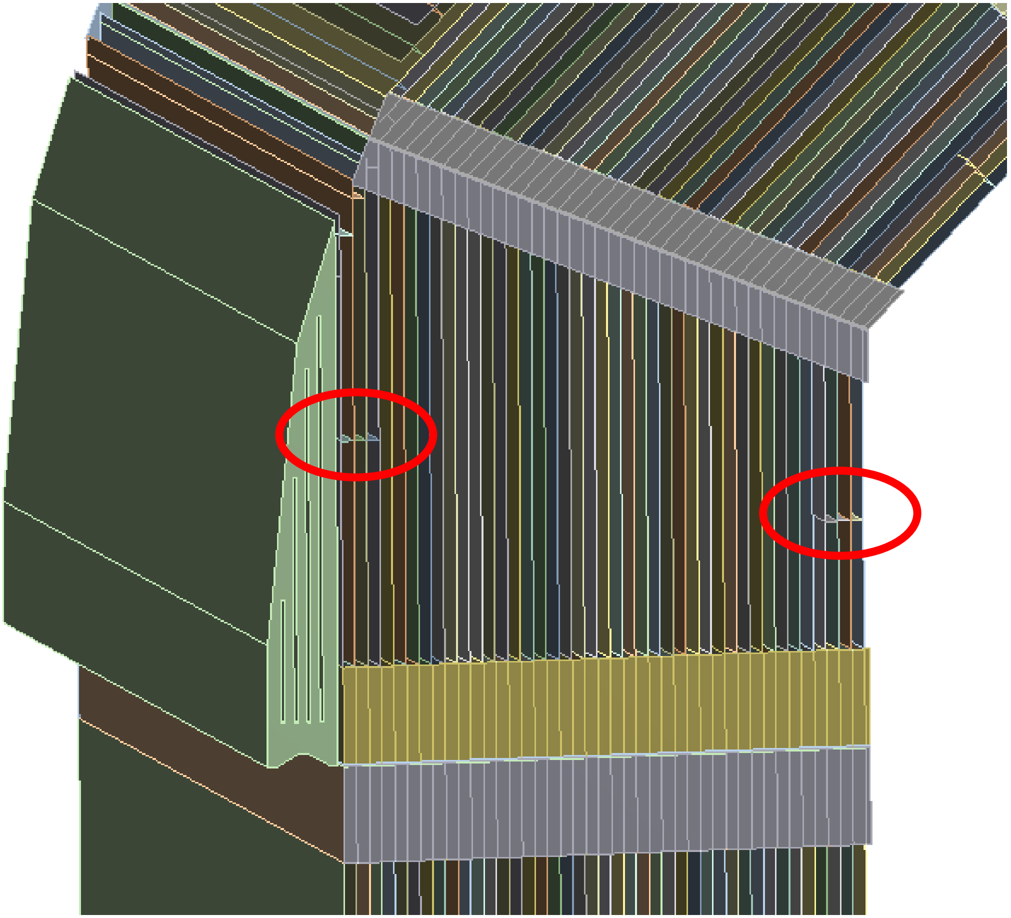
Case 6 – Geometry

- As Case 2, coverplates with double width and thickness (t=30mm, w=400mm)



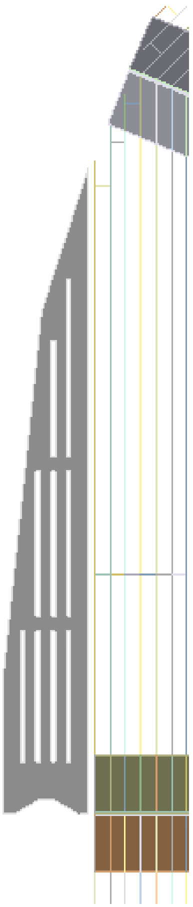
Case 7 – Geometry

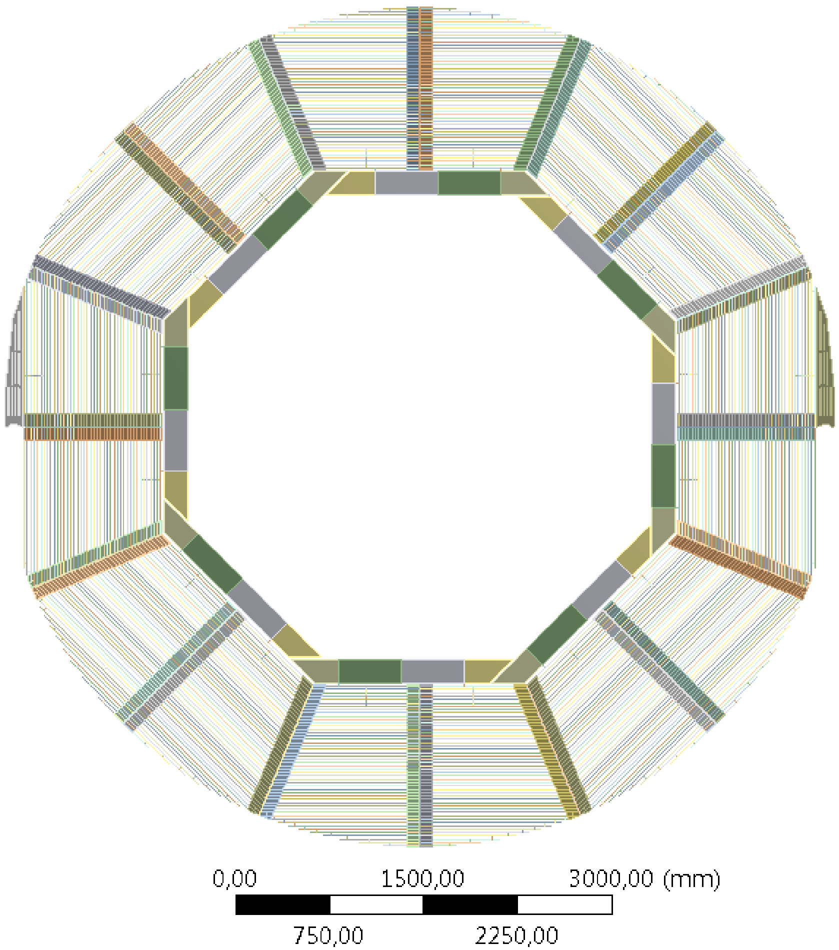
- Less Spacer, small Coverplates (t=15mm, w=200mm) and wider Coverplates (t=15mm, w=400mm)

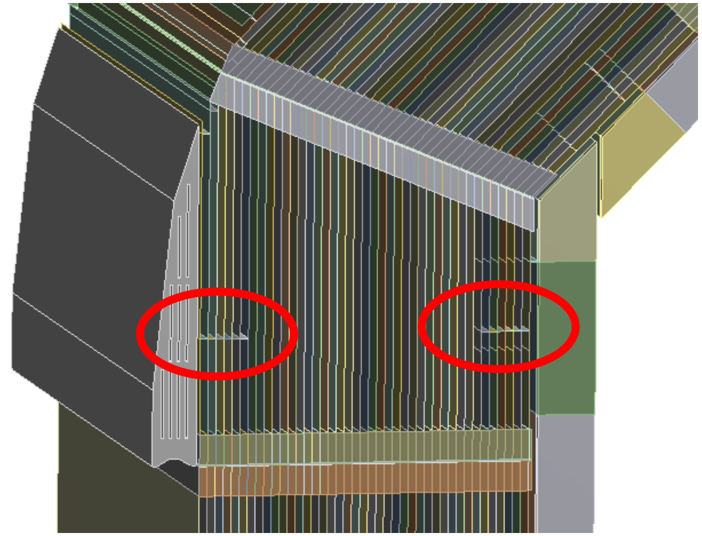


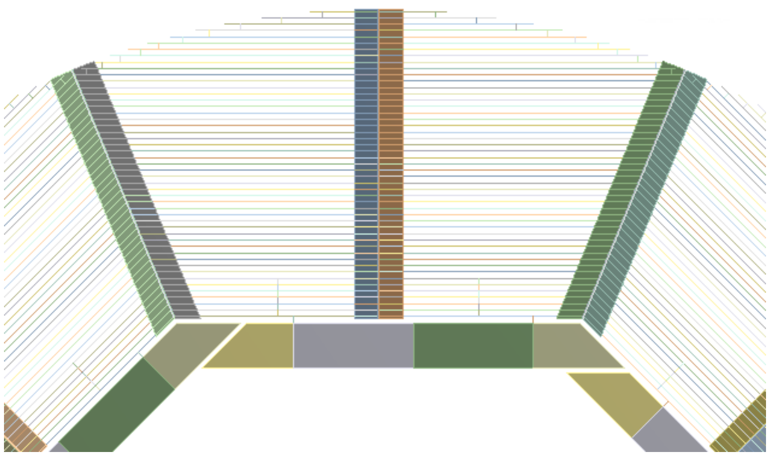
Case 8 – Geometry

- As 2., less Spacer, all Spacer across 6 layer, re-inforced support, ECAL-Geometry



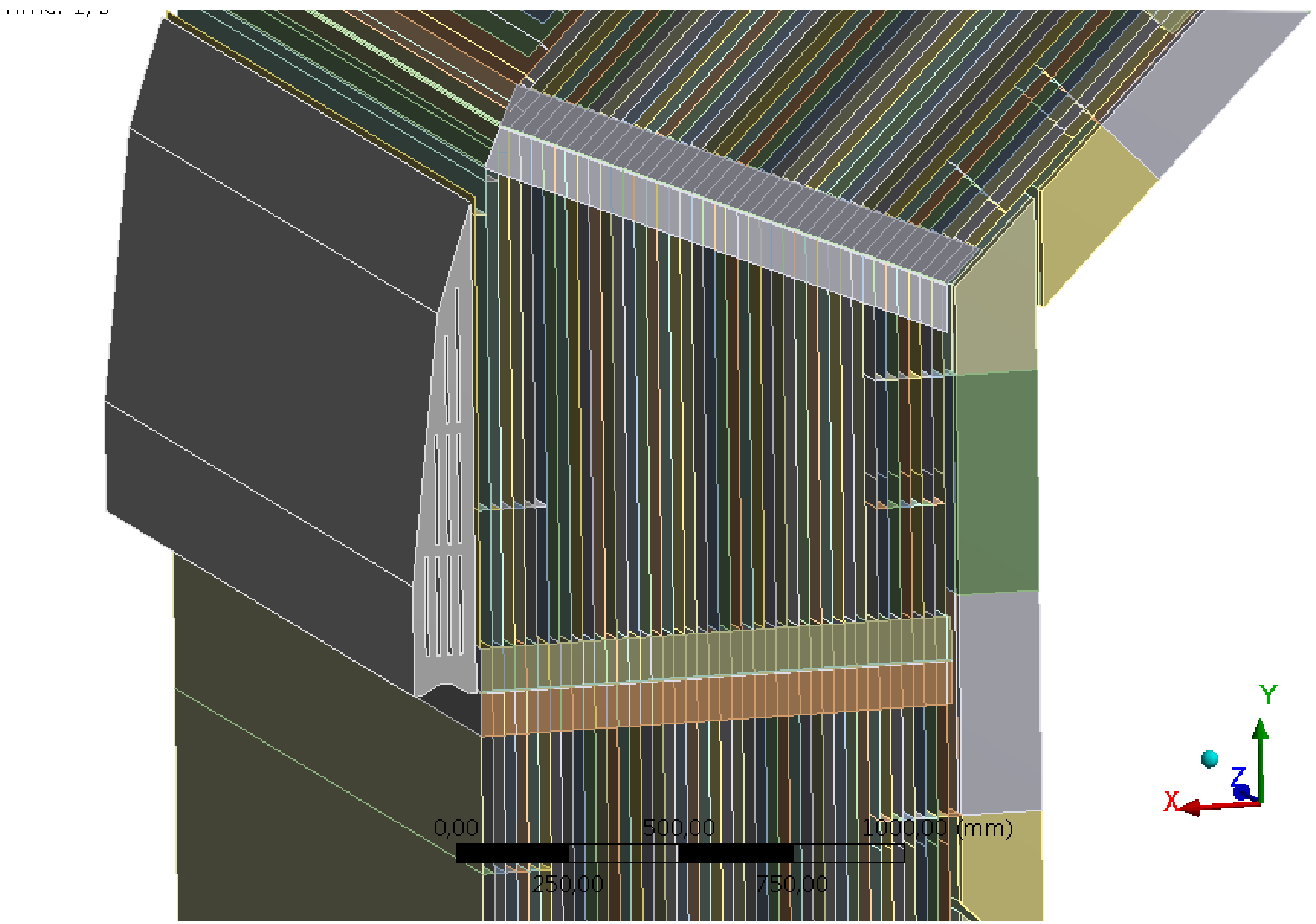






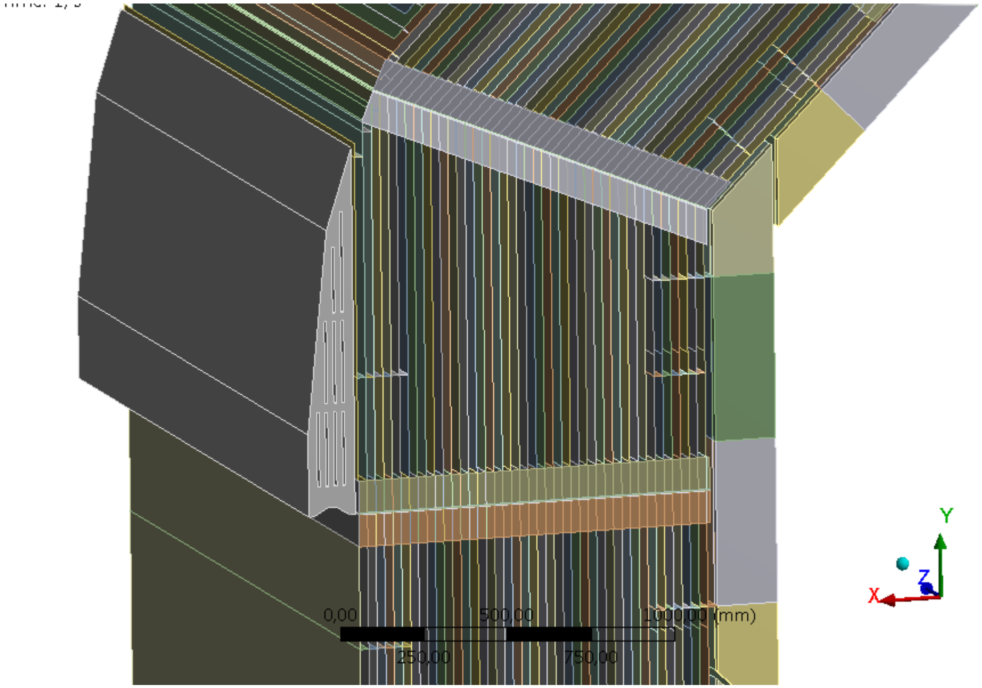
Case 9 – Geometry

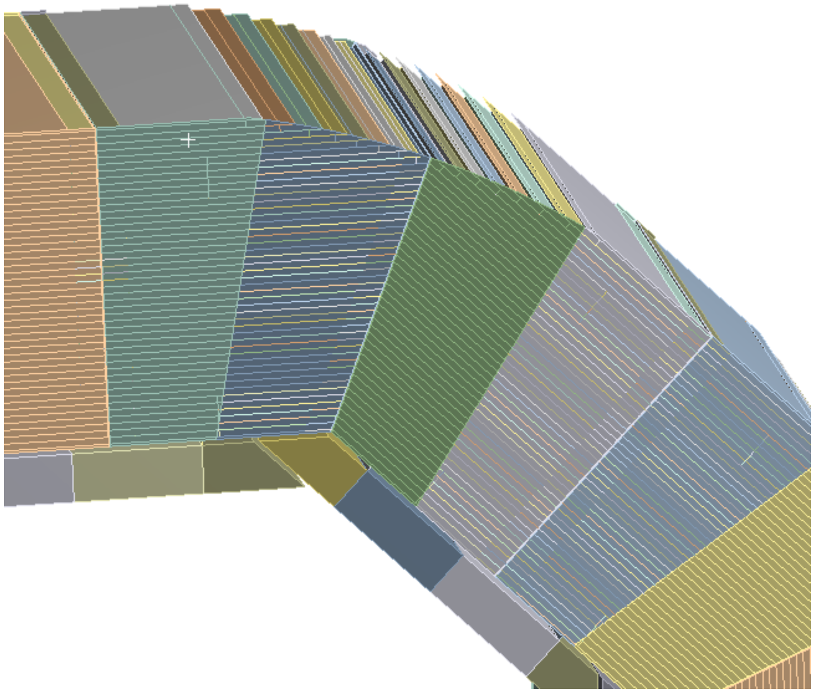
- As 8., all Spacer across 6 layer, ECAL-Geometry



Case 10 – Geometry

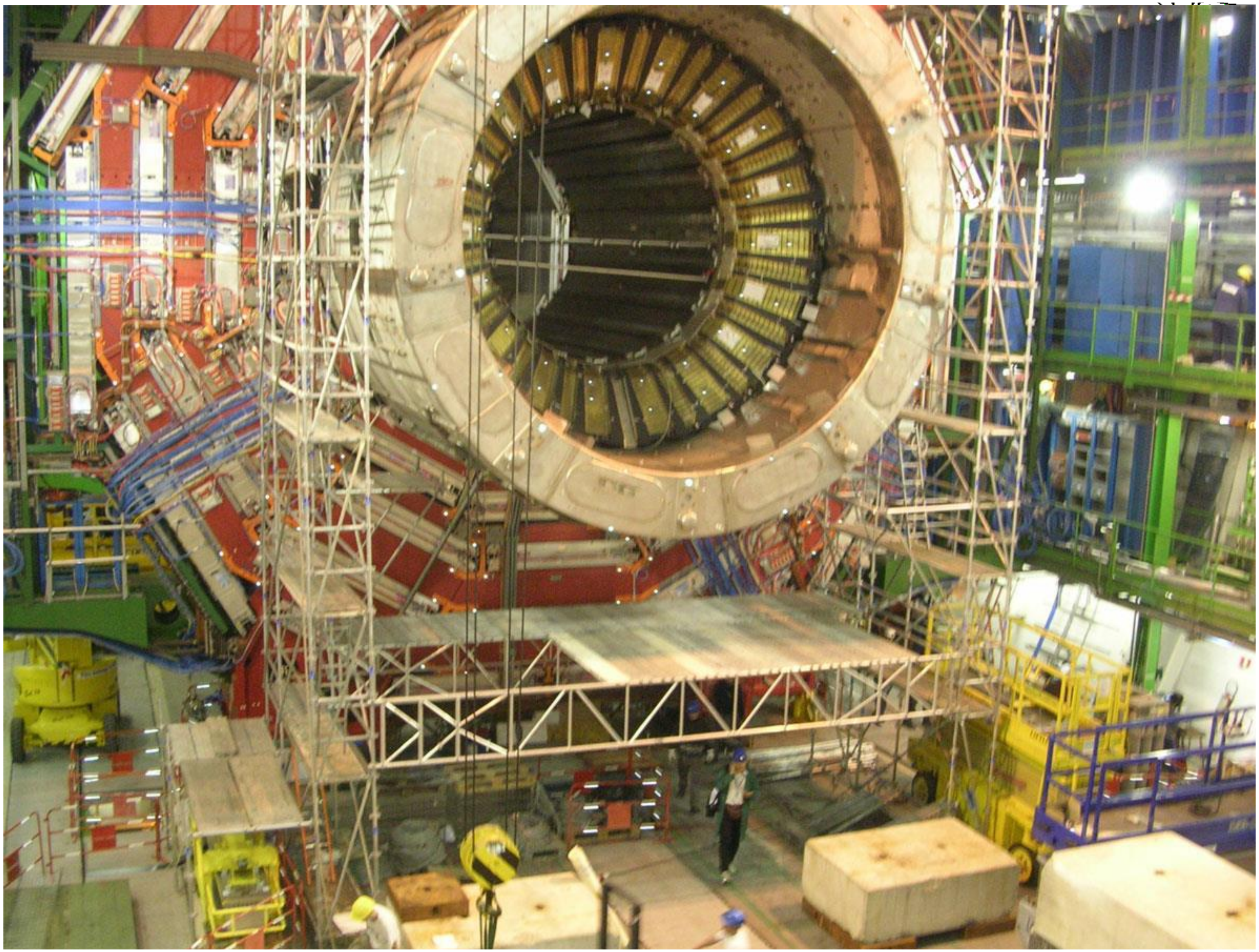
- As 9. and Backplates (t=10mm, same in case 3.)
- Left:Coverplates, Support and ECAL
- Right: Backplates (connecting to segments, splitted/sliced due to needed FE-Model structure for Substructuring and ECAL





CMS HCAL

CMS HCAL



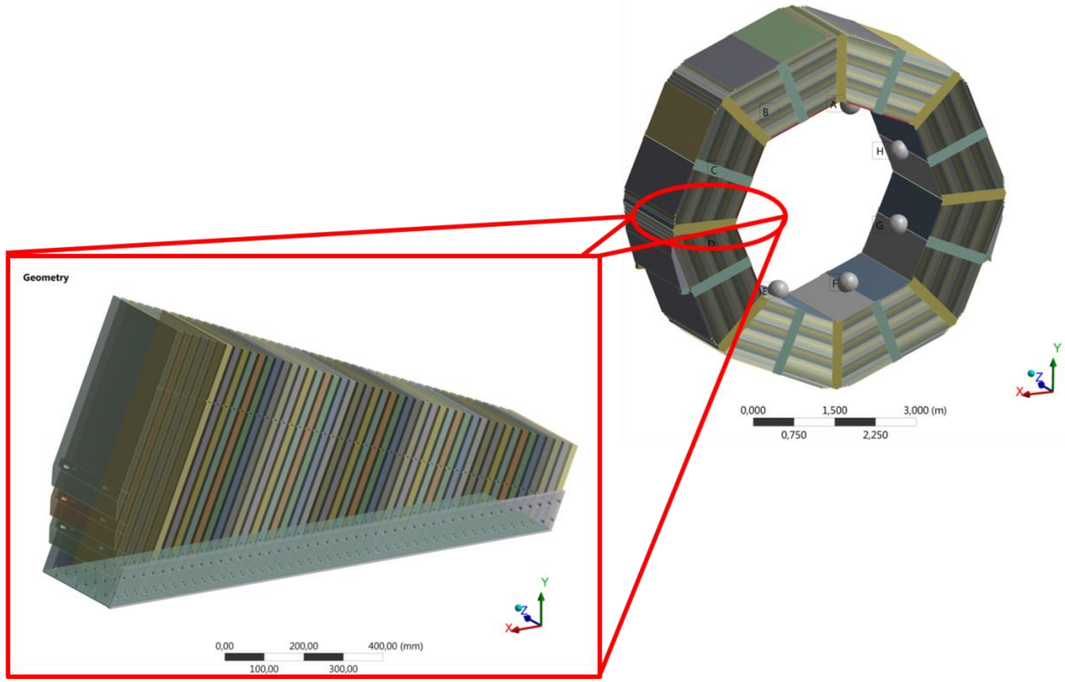
How to get the Stress in single screws of AHCAL-Segments? – The general Plan and Submodeling

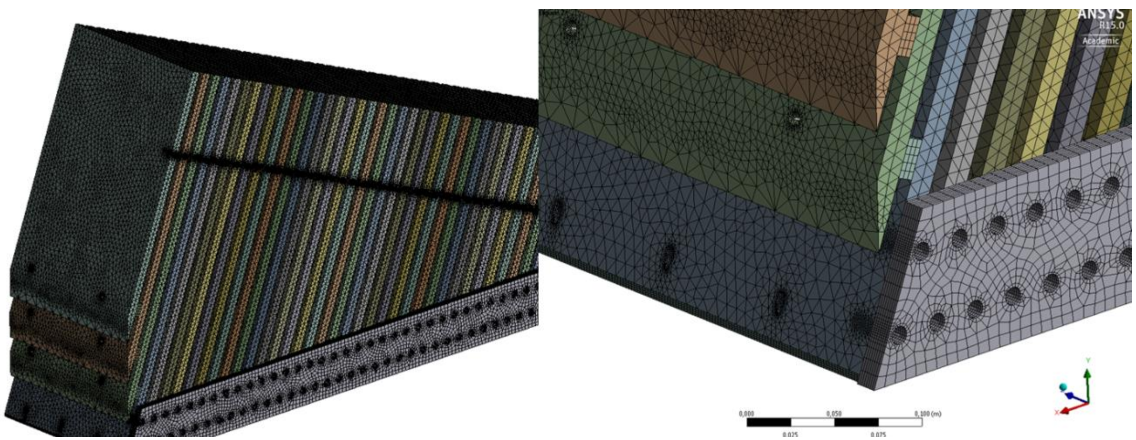
- Simplification of FE-Models reduces the accuracy of local stress phenomena => Submodeling-Method
- Here: global/full AHCAL FE-Models uses Shell-Elements to reduce the overall problem size
- With the help of the Submodeling Method the total displacements on the full FE-Model ca be tranfered to the detailed 3D FE-Model
- In the cases the Substructuring Method (and their special Superelements with Master Nodes on the boundary faces) for our dynamic analyses will be used, the FE-Models are set up in that way to allow the usage of the Submodeling Method every time

How to get the Stress in single screws of AHCAL-Segments? – The general Plan and Submodeling

> The principle:

- Built-up a global FE-Model (geometry, boundaries, loads) with special cut-boundaries included
- do the rough calculation of deformation information and
- export these deformation information from the cut boundary to an external file



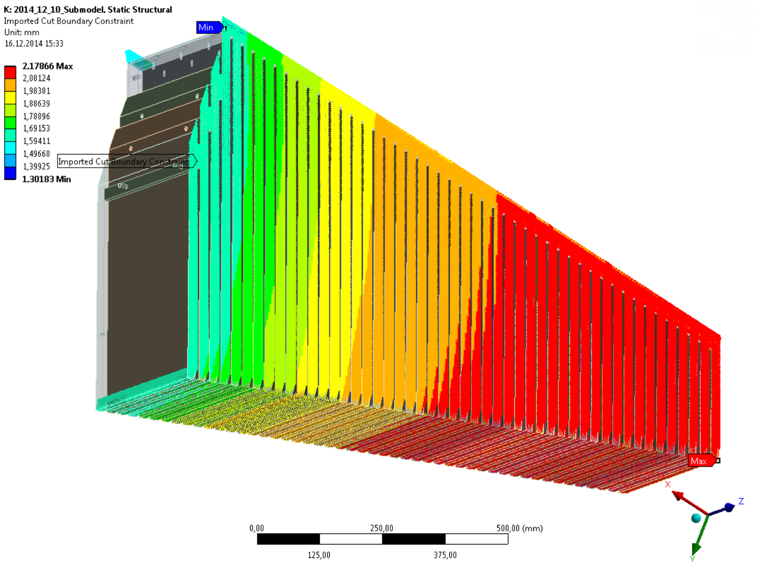


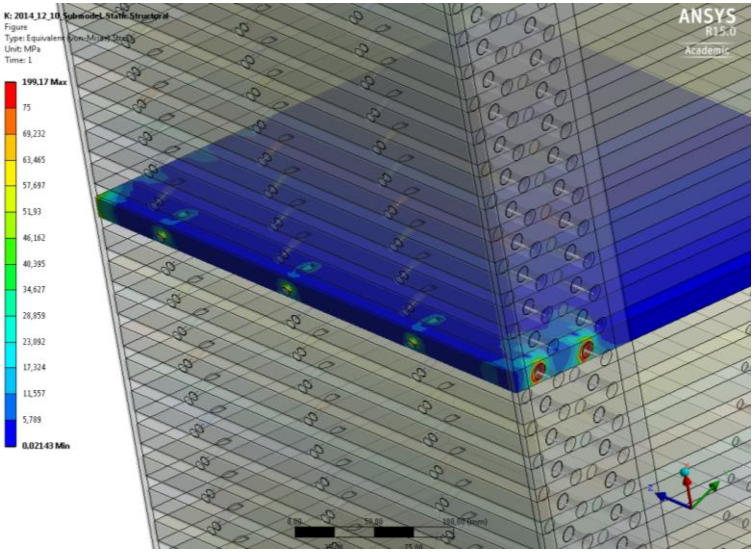
> Valid for all analyses types

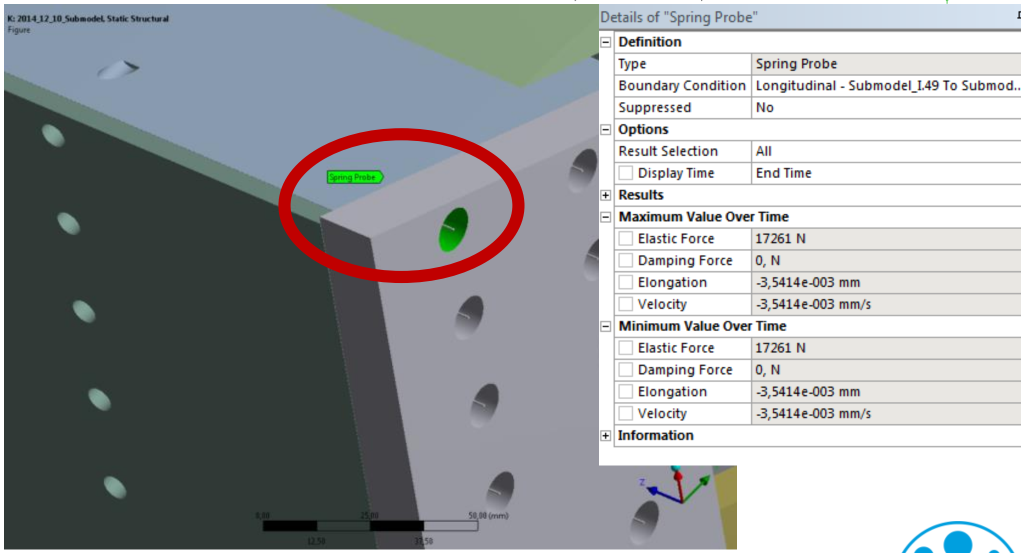
> E.g.: the detailed FE-Model with a fine mesh and about 6,4e6 Nodes

How to get the Stress in single screws of AHCAL-Segments? -- The general Plan and Submodeling

- Built-up a detailed FE-Model inside the cut boundaries (in the same location with regard to global coordinates) and mapping of deformation information onto these cut boundaries
- After a succesful solution/solve, e.g. mechanical working loads on single screws can be investigated







Case 10 – Stresses in a 3D Submodel

- Screws modeled as spring elements with preload about 30kN, cross-sectional area and stiffness in N/mm according to M12 specific data
- Contacts between the coverplate and the segment plates defined as a frictional contact:
  - Friction coefficient about 0,15 (steel to steel, dry without lubrication)
  - A non-linear contact with the possibility to lift off
    => important to investigate wether the preload is sufficient to clamp all plates tight to each other wiithout sliding effects/lift off
- Example of 3D Submodel (left imported displacements, right Stresses)